DOCTOR OF PHILOSOPHY

The need for and the use of three dimensional simulation in dental education

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Award date:
2017

THE NEED FOR AND THE USE OF THREE DIMENSIONAL SIMULATION IN DENTAL EDUCATION.

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THESIS SUBMITTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN DENTAL EDUCATION

SCHOOL OF DENTISTRY

UNIVERSITY OF DUNDEE

2017

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ACKNOWLEDGEMENTS

I would like to thank everyone who helped me during the process of this PhD. First, to my dear supervisors, who made this possible and mentored me all along this academic journey: Dr. Sean McAleer, Dr. Andrew Forgie and Dr. Andrew Mason.

Sean, many thanks for every single piece of feedback, all your help with my writing and helping me straighten-up my ideas.

Andrew F., thanks for always making me see things from a positive side and supporting me on every single issue encountered.

Andrew M., thanks for your support over years. Thanks for hearing me every time I knocked your door and giving me time even when you were busy.

Also, I would like to thank Miss Emily McDougal and Mr. Mark Roughley for producing the 3D interactive models and helping me with the visuals for this project.

I would like to thank Mr. Simon Scott, for his flawless clinical photographs and great disposition.

Thanks to Mr. Gavin Revie for his advice on the statistical issues related to this project.

I would like to acknowledge Professor Samuel Cadden, who invited me to take part in this project. My sincere best wishes to him in his retirement.

I would like to thank my sponsor, CONICYT, for giving me the possibility to pursue this dream and fund my stay in Scotland.

Great thanks to all the volunteers who took part in this study, without your help this project would not be possible.

Finally, but very importantly, I want to thank my family and friends. Especially my beloved husband Marco Antonio for his support, patience and encouraging me to carry on every day. I want to thank my sons, Antonio and Sebastian, for working with me and allowing me to write and finish this dissertation even when they wanted to play with me. I also want to thank my parents, Jeannette and Pedro and my brothers Pedro Luis and Diego, for their support along the years far away from home. Thanks mum and dad for believing in me and making of me the person who I am.

DECLARATION

I declare that this thesis has been composed solely by myself and that it has not been submitted, in whole or in part, in any previous application for a degree. Except where it states otherwise by reference or acknowledgment, the work presented is entirely my own.

Signed…………………………………………………………… Date………………………………

Paulina Isabel Poblete Pacheco

CERTIFICATE

I hereby certify that Paulina Isabel Poblete Pacheco has fulfilled the conditions of ordinance 39 of the University of Dundee and is qualified to submit this thesis for the degree of Doctor of Philosophy in Dental Education.

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DEDICATION

My work is dedicated to my husband Marco Antonio

and my sons; Antonio and Sebastian.

ABSTRACT

Despite the growing number of publications relating to three-dimension (3D) and education, the need for this technology, its usability and educational impact are not clear for dental education with the exception of haptics. The first stage of this doctoral research used a mixed method to examine key stakeholders' views about those areas of dentistry that would benefit from having a 3D learning resource. Two hundred and five dental students, academics and graduates responded to the survey (134 females and 71 males). Results suggested that several areas of dentistry would benefit from 3D animations or simulations. Anatomy of the Temporomandibular joint (TMJ) was the top priority area from the list of the identified items.

After identifying the areas of need, the researcher determined principles for e-learning and instructional design; followed by a feasibility study that identified a suitable authoring tool for the construction of a resource capable of containing 3D interactive models. A multidisciplinary team headed by the researcher developed the first iBook addressing the Tooth Morphology of the permanent dentition. The researcher collected feedback from users of the tooth morphology iBook using a mixed method experimental study, which included a questionnaire and a focus group session. Scottish and Chilean participants (n=138), from the University of Dundee and The Andes respectively, indicated that the iBook was well designed and it was a valuable resource where they could interact with the 3D models

provided. These results informed the construction of a second iBook addressing the anatomy of the temporomandibular joint (TMJ) and masticatory system.

Two versions of the TMJ iBook were created: a 3D version containing interactive models and a 2D version holding images. The researcher designed a comparative study including a pre-test/post-test intervention and a questionnaire to compare results from the two groups (3D and 2D). Twenty-seven first-year and thirty-two third-year dental students from the University of Dundee participated. The results of the intervention revealed statistically significant improvements in the results of first-years students who used the 3D version iBook compared to those who used the 2D one. The third-year cohort results revealed no significant difference between the 2D and 3D groups. The researcher arranged two focus group sessions to gain a deeper insight into the results. From those who took part in the intervention, eleven volunteered for the focus group sessions (six first years and five third-years). Results indicated that the TMJ iBook was a valuable resource for learning. Regardless the year of study, all participants preferred the use of the 3D interactive models as they had the potential to simplify visualisation and orientation, and enhance motivation for learning.

Three key findings arose from this doctoral study. The first one indicates that several areas of dentistry would benefit from 3D resources and they would satisfy dental students' needs. The second conclusion suggests that iBooks are a powerful, straightforward and valuable resource for creating new e-learning interactive material capable of displaying 3D models. The final finding suggests that the use of 3D interactive models have the potential to enhance learning in novice dental students, while they are capable of motivating and aiding visualisation both in junior and experienced students.

RELEVANT CONFERENCES PUBLICATIONS AND PRESENTATIONS

The present doctoral research has been presented at interactional conferences for oral and poster presentations.

1. **Abstract selected for poster presentation ADEE 2014**

Identifying areas of need for three-dimensional virtual learning resources in dental education

(Poblete P., McAleer S., Forgie A., Mason A.)

Although dentistry is mainly a three-dimensional (3D) discipline, there is little clarity as to which areas of dental education could benefit most from the creation of e-resources to facilitate learning of 3D concepts.

Aim: This study aimed to determine those topics best suited to having such resources.

Materials and Methods: A mixed method experimental design was employed over two phases. The first stage aimed to identify dental students' and academics' perceived areas of need for 3D resources in dental studies. Ten focus group sessions were conducted with University of Dundee postgraduate and undergraduate dental students and academics. Thirty-six individuals participated, revealing 97 areas of dentistry appropriate for 3D resources. These results were used to construct a Modified Delphi Survey which was used to prioritise the items identified in phase 1. This survey was sent to 767 final year Scottish dental students, new dental graduates and academics from the Universities of Glasgow,

Aberdeen and Dundee. Additionally, 202 undergraduate students, 157 postgraduate dental students and 170 academics from the University of The Andes, a Chilean University, were included. In total 1296 invitations were sent; from those two hundred and five responded.

Results: The results revealed that detailed anatomy of the head and neck such as the temporomandibular joint, dental anaesthesiology, dental clinical skills techniques, dental occlusion and mandibular functioning are top priorities. When broken down by gender no statistical differences were found in highly ranked items. When comparing graduate dentists with undergraduate students statistical difference was found in only one of the highly ranked item analysed: Head and Neck Growth and Development ($p<.05$). A 3D learning resources for this last item was perceived more beneficial by academics than by dental students for dental education.

Conclusions: The overall results suggest that there are several areas that would benefit from 3D digital learning resources.

2. Abstract selected for oral presentation PEF IADR 2014

Three-Dimensional Virtual Learning Resources: Comparing Perceived Needs in Two Countries

(Poblete P., McAleer S., Forgie A., Mason A.)

Three dimensional resources for education have become more common in the last decade. In dentistry many of these have been created by enthusiastic dental academics keen to facilitate student learning. Yet, it is not totally clear if these 3D resources fulfil students' needs. The demand for this technology has grown globally, thus determining the perceived needs of different dental students and academics is of great interest.

Aim: This study aimed to compare the perceived needs of Scottish dental academics and final year dental students with those from a Chilean dental school.

Methodology: A modified Delphi technique was used. A list of topics was sent to 788 final year dental students and dental academics from the Universities of Glasgow, Aberdeen, Dundee and The Andes (Chile). Participants were asked to rank the perceived benefit of a list of topics from one to five. One hundred and forty-nine responded. Frequencies of responses were divided into "beneficial" (scores four and five) and "non-beneficial" (scores one, two and three). Topics scoring >85% of perceived benefit were analysed using Fisher's Exact tests.

Result: Comparisons among Scottish Universities revealed no significant difference in responses despite differences in the curriculum structures. Scottish and Chilean responses showed minor differences. Chilean participants' perceived it beneficial to have a 3D digital resource for Biomechanics in Orthodontics and Orthognatic Surgery; topics not considered as beneficial by Scottish participants (p: 0.0171; 0.0078). Masticatory Muscles Anatomy and Physiology was considered beneficial by Scottish compared to Chileans ($p<.05$). The top item for both groups was Temporomandibular Space Anatomy.

Conclusion: As only small differences were observed; these results suggest that students and academics from the selected dental schools have similar perceived needs for 3D virtual learning resources despite curricular and cultural differences. Top priority items among the four dental schools were mostly the same.

3. Abstract selected for oral presentation ADEE 2016

The impact of 3D versus 2D iBooks

(Poblete P., McAleer S., Forgie A., Mason A.)

Aim: The primary aim of this study was to compare dental students' evaluation of two iBooks (delivered using Apple iPads) addressing the anatomy of the temporomandibular joint (TMJ) and the masticatory system: one using 3D visual interactive elements and the other one using a series of 2D images representing the same structures. The secondary aim was to explore users' perceptions in order to determine if there are benefits associated with 3D.

Materials and Methods: A mixed method was used. First year dental students from the University of Dundee were invited to participate in this study. The first stage was a randomised control group comparison using a pre-test/post- test method. Scores from the pre-test/post- test were collected as well as the time each participant spent using the resource. The second stage was a focus group, where data was collected by means of an audio record.

Results: Twenty-seven students took part in the study, thirteen used the 2D iBook and fourteen used the 3D iBook. Results for pre-test/post-test for each group were: 2D iBook: 9.2 +/- 3.3 SD and 9.7 +/- 3.3 SD, 3D iBook: 8.4 +/- 3.4 SD and 11.2 +/- 2.5 SD. A two by two-way factorial ANOVA test showed a significant interaction between pre-test/post-test and the 2D and 3D learning method ($p<0.05$). The mean time per group students used the iPads were: 2D: 21 minutes; 3D: 29 minutes. The correlation between time spent and score improvement was non-significant. Framework analysis of the focus group data showed students were highly motivated and felt more confident with their responses when using the 3D learning resource.

Conclusions: 3D learning resources can be a valuable and effective resource for studying the TMJ and the masticatory system and are capable of enhancing motivation and confidence in junior dental students.

1 INTRODUCTION

The rapid advance of technology has impacted all areas of life including education. Dentistry, following this trend, has seen progress in the use of three-dimensional (3D) simulations, animations, haptics and imaging (Mattheos et al., 2008). The popularity that 3D has gained is reflected in the multiple publications addressing the topic (e.g. Codd et al., 2011; Petersson et al., 2009; Mitov et al., 2010; Wright et al., 2010; Vuchkova et al., 2011; Prinz et al., 2005; Hariri et al., 2004). However, the justification of its need, use and impact on education is still not yet fully understood.

The second chapter of this dissertation presents a comprehensive literature review that contextualises this study. First relevant information from educational theories is presented, followed by how technology links with education. Then, the researcher discusses the current educational trends for dentistry followed by an analysis of those studies linking dentistry with the use of 3D for education.

The third chapter explores the views of key stakeholders about which topics in dentistry would benefit from 3D learning resources. Emphasis was placed on students' perceptions in relation to topics that need 3D to facilitate learning. This chapter identifies those areas of dentistry that would benefit from a 3D e-learning resource using a learner-centred approach.

The fourth chapter is an options appraisal of different e-learning authoring software packages. This appraisal identified the most suitable one for use in the main research study which develops e-learning resources that contain 3D animations and simulations.

The fifth chapter details the main principles and instructional design features required for the construction of an effective learner-centred e-learning resource.

Chapter six prioritises the topics identified in chapter one that have a clear need for the creation of learner-centred e-learning resources containing 3D animations and simulations.

The seventh chapter of the thesis describes in detail the authoring process of the first learning package.

Chapter eight assesses students' perception of the resource using a mixed method approach.

Chapter nine describes the development of the second e-learning resource utilised and describes the construction of a 3D and a 2D version of the e-learning tool.

Chapter ten details the experimental method undertaken to compare both e-learning resources. Results of this chapter provide an answer to one of the key issues surrounding the use of 3D animations and simulations for education: do they work for education and if so, for whom?

The aims of this thesis are:

- To identify topics in dentistry that would benefit from 3D learning resources.
- To prioritise the topics that would benefit from 3D learning resources.

- To explore students' perceptions of an iBook about Tooth morphology.
- To determine if there are benefits of using interactive 3D models within learning resources.
- To compare the use of two iBooks (3D vs. 2D) with two groups of dental students (novice and advanced students).
- To explore students' perception about the use of 3D for learning in dental education.

The final section of this doctoral dissertation discusses the findings of the overall study, highlighting the importance of the study and its contribution to the knowledge and understanding. Additionally, the researcher provides her personal reflections and views on her doctoral experience.

2 LITERATURE REVIEW

2.1 INTRODUCTION OF THE LITERATURE REVIEW

This chapter presents key concepts, theories, and evidence of how 3D technology links with learning, with a focus on dental education. The chapter starts by discussing educational theories that are crucial to understanding how learning occurs, followed by important principles of how adults learn. Then, there is a brief section on how technology has interacted with education in the last few decades, and one on how 3D technology has impacted dental education. The final section gathers evidence of how 3D technology has been used in dentistry in recent years, revealing two gaps that are addressed by this doctoral study.

2.2 EDUCATIONAL THEORIES

When studying the art of learning it is important to explore different assumptions of how the process occurs. Several authors recognise the importance of theory as a foundation for strong, high quality, efficient and profound learning in medical education (Arogundade, 2011; Gibbs et al., 2011; Rees and Monrouxe, 2010). Nevertheless, there are many learning theories described in the literature where their applications and principles vary depending on the learning scenario. Understanding the theory of learning is key to promoting education. Therefore, it is appropriate to explore those ideologies whose principles have an influence of how learning with 3D technologies occurs.

Constructivist theory looks on the learner as an active, self-aware, self-motivated and responsible subject in charge of constructing their learning (Kaufman, 2003;

Collins, 2004). Under this theoretical framework, the tutor is considered a facilitator who passes on experiences to students. The tutor's role is to guide and support the learner so they can become an active and independent learner. Social constructivism theory is very similar but adds a social component, which plays a major role in the process. In social constructivism learning occurs when the learner interacts actively with the social environment and the learning object (Söderström et al., 2012).

Cognitivist theory believes in a learner who is capable of thinking, processing information and solving problems by applying what was learned (Ertmer and Newby, 1993). The educator has a role of "demonstrator" promoting the independence of the student towards the accomplishment of effective and reflective learning (Swanwick et al., 2010). The social cognitive theory recognises the importance of the individual's attitudes, values, goals, experiences and knowledge in the learning process (Bandura, 2001). Within the context of medical education, Mann (2011) agrees with the social cognitive theory, and emphasises the importance of the social and professional aspects which are critical to the learning process.

Holistic theory believes that knowledge has three facets: explicit, implicit and emancipatory (Yang, 2003). Explicit knowledge refers to the facts, principles, and formulas. Implicit knowledge refers to experience and practice of the individual, setting knowledge in the behavioural domain. The emancipatory facet relates to the inner motivation of a person, specifically with their individual conscience and beliefs. Yang (2003) proposes that the interaction of the three facets allows the learning process to occur. Similar to constructivism theory, individuals have the opportunity to develop their learning, but within the holistic approach, the social and the inner aspect of the individual are considered.

Experimental learning theory views learning as a process where individuals transform their learning based on experiences. Experimental theorists believe that learning occurs when the learner turns experiences into knowledge. The learner is seen as an individual capable of experimenting, reflecting, thinking and acting (Kolb and Kolb, 2005).

Another theory described in the literature important for the learning of 3D virtual simulations is the multimedia theory for education. This theory suggests that learning occurs when the learner does a mental construction based on provided words and pictures (Mayer, 2002). Mayer and Moreno (1998) blended the cognitive learning theory with the multimedia one. As a result, the authors present the "cognitive learning theory for multimedia" supported in three assumptions. First, is the information should be transferred using a dual channel: audio and visual to facilitate its integration with previous knowledge (Mayer and Moreno, 2002). Secondly, there is a limited capacity of processing this information by the fore mentioned channels. This second assumption aligns with cognitive load theory which states that humans have two types of memory: long and the short-term memory (Paas et al., 2003). The stimulus should interact in the limited short-term memory without overloading it to obtain learning in the unlimited long-term memory. When overloading takes place, retention in the long-term memory fails to occur. The final assumption relates to the cognitive process, suggesting that the learner needs to be active in practice and interact with the resource (Mayer and Moreno, 2002).

In 1985 Deci and Ryan (1985) established the foundations for the self-determination theory (SDT). This theory proposes that an individual has the motivation to decide on their acts, choices, and likes. Self-determination theory suggests that the learning process is influenced by the type of motivation the individual has (Ryan and Deci, 2000). Two main types of motivation were explained by the authors: “autonomous” motivation and “controlled” motivation (Ryan and Deci, 2000). “Autonomous” motivation includes inner motivation and those external motivations that are chosen by the individual. Inner motivation corresponds to personal drives or desires that move the individual to accomplish something. The well-accepted control motivation includes those external stimuli that have a positive influence in a person, for example being motivated to perform well at a job to get a promotion. The “controlled” motivation are those external stimuli that the individual considers coercive (Vansteenkiste et al., 2006). SDT considers the “autonomous” motivation to be a positive driver of learning.

The above theories have a relationship with the learning method used in this study. Constructivist theory recognises the importance of an active learner, who is the main participant in the processes. It highlights the importance of rational thinking for the process, while the holistic approach includes the inner domain of the learner. Experience and motivations are two main concepts that have a direct impact on the learning process. The experimental learning theory and the self-determination theory address these two concepts in detail. The cognitive learning theory for multimedia provides principles for a correct instructional design process. These principles were used for the development and authoring process of the 3D e-learning resource.

All the fore mentioned theories manage to explain how the learning process occurs; some putting more emphasis on certain concepts than others. However, to promote sound education, it is also important to revise those adult learning principles, so that they can be used in practice.

2.3 PRINCIPLES OF ADULT LEARNING

Knowles et al. (2015) defined learning as the process of gaining knowledge and experience. Yang (2003) explained learning in more detail as: *"… The process whereby knowledge is created, acquired, transformed, converted, or utilized in a different context from its origin."*

Learning focuses on the person who is experiencing the process. Therefore if the individual is a child, the art of teaching is called pedagogy; while if the learner is an adult it is known as andragogy (Knowles et al., 2015).

2.3.1 ADULT LEARNING

The term andragogy was originally coined by German educator Alexander Kapp in 1833. Malcolm Knowles, the father of andragogy, proposed six characteristics of how adults learn, bringing together education and practice (Table 2.1). The adult learning principles presented by Knowles aim to enhance the learning experience (Knowles et al., 2015). Adult learning principles are statements that drive adults' learning.

Table 2.1: The andragogic model accordingly to Knowles et al. (2015)

The adult learner:
Needs to know what it is going to be learned
Is self-directed and responsible for their own decisions
Shows readiness to learn and is actively involved in the process
Is task orientated
Is moved mainly by inner motivations
Bases their learning in experience

2.4 ANDRAGOGY PRINCIPLES IN MEDICAL EDUCATION AND LEARNING STYLES

In principle, adult learners need to recognise the importance of what is going to be learned. Additionally, learning needs to be meaningful and relevant (Collins, 2004). When using these principles learning becomes effective. Being aware of how meaningful a topic is, will activate the learner's inner motivation; as a consequence, the learning process becomes active, effective and deep (Swanwick et al., 2010). On the contrary, when a topic seems to be unnecessary, unconnected to real problems or meaningless the importance of it decreases, and the learning process becomes superficial and inconsistent. Problem-based learning (PBL) technique is an effective way to relate clinical scenarios with theory and practice, demonstrating meaningfulness to the student (Hmelo-Silver, 2004). A PBL methodology can demonstrate to the student why they should learn something by using applicable and real cases related to their training. Such an approach can enhance adult learning as it contributes to a student-centred method (Davis, 1999).

Another important learning principle that drives adult education is self-direction. This principle has its basis on the assumption that adults are responsible for what they learn. Theoretical models such as constructivism, cognitivism and social are commensurate with the principle of self-direction (Swanwick et al., 2010). Self-directed learning allows the learner to reach higher levels of competence, as he/she has to assess when, how and what to learn, while the teacher becomes a demonstrator or a guide (Kaufman, 2003). Controversy exists around the self-direction principle, as it has been argued that new learners are not able to recognise what needs to be learned (Jennings, 2007). Also, when it comes to learning, it has been suggested that novice learners do not have enough expertise to make a good decision (Jennings, 2007). Although this makes sense, the self-directed concept does not refer to content, but to the attitude the learner should have towards the acquisition of new knowledge. The self-directed principle involves critical thinking, as the learner needs to be able to solve problems (Mann, 2011). Tutors can encourage, support and guide self-direction in a learner. However, learning will occur based on the student's own work (Park et al., 2007). On the other hand, it is important to recognise that not all adults have the same capacity for self-direction (Arogundade, 2011).

Kaufman (2003) believes that when reflection occurs, the learner reshapes abilities in their training. Reflection can be defined as an instance of enhancing awareness, were the learner has the opportunity to think about their assumptions, values and intentions placed into practice (Tsang, 2007). This analytic process allows new perspectives to emerge, bringing together theory and practice (Swanwick et al., 2010). Mann (2011) considers that collective and personal reflection adds significant value to the learning process; thus, it seems that good communication is of great importance. Evidence from the field of medical education shows that task-based learning (TBL) is a successful strategy that the learner can use to promote reflection on their actions and take responsibility for their learning (Harden et al., 1996). In TBL learning occurs when the student completes a task, allowing them to comprehend and understand the mechanisms and processes involved in the task bringing together theory and practice (Harden et al., 1996). Moreover, Tsang (2007) believes that internal and external dialogue is essential for reflection. Establishing an active and efficient dialogue with students when discussing learning outcomes, developing topic content, clarifying doubts or sharing experiences, will promote communication and an effective internal and external reflection. Also, this practice will allow the teacher to discover features of their students' personalities and strengthen the learner-teacher relationship. However, reaching a meaningful reflection can be difficult when the learner does not know how to do it. It has been suggested that to obtain effective reflection of novice students, the tutor can set a structure, make it compulsory or even assess it (Buckley et al., 2009).

Motivation and adult learning are closely related (Mann, 1999). Traditionally, two major types of motivation have been described: intrinsic and extrinsic motivation. Mann (1999) recognised that the two types of motivations co-exist. Kusurkar et al. (2011) explain intrinsic motivation as the inner desire that a person has to do or accomplish something, determined by self-determination or personal drive. Meanwhile, extrinsic motivation is driven by the external factors that affect the decisions of the learner (Kusurkar et al., 2011). Self-determination theory suggests that both types of motivation are necessary for the learning process (Vansteenkiste et al., 2006). Vansteenkiste et al. (2006) explain that intrinsic and well integrated extrinsic motivation results in the “autonomous” motivation, which has an effect on how the individual learns. It has been stated that motivation to learn has a direct relationship with ambitions and goals (Knowles et al., 2015). Motivation is also closely related to the principle that suggests that adult learning is task orientated.

The last principle proposed by the andragogy model states that learning occurs as a result of the learner’s previous experiences. The acceptance that experience can enhance the learning is part of various educational theories (Mann, 2011). Moreover, Knowles et al. (2015) claim that the way adults learn relies on the analysis and use of their previous experiences.

Another point to consider is the recognition that every learner is unique. Kolb described four types of learning style: diverging, assimilating, converging and accommodating (Kolb, 1984).Learning styles suggested by Kolb and Kolb (2005) as in simple words the preferred way of learning for an individual. The learning style theory assumes that the learning process depends on a particular learning method i.e. how the learner gets the information which could be via audio, video or multimedia. For instance, if a person likes to have a visual stimulus, then learning from a video could be easier than learning using an audio. Despite Kolb’s suggestion of the existence of learning styles, there is still a lack of evidence about their actual benefits. Coffield et al. (2004) believe that there are still massive gaps in educational research related to learning styles. Newcombe and Stieff (2012) concluded that individuals cannot be defined as “verbal” or “visual” learners. The authors argue that students apply multiple strategies for learning at the same time.

Overall, the adult learning process is multifactorial and several principles work together in the process. The way that adult education is understood is a result of a pedagogical shift due to the integration and relationship of theory and practice (Mann, 2011). However, this change discussed by Mann (2011) has also been influenced by the advance of technology within education.

2.5 EDUCATION AND TECHNOLOGY

2.5.1 INTRODUCTION

Education and technology are two massive concepts, and there is plenty of information relating them. This section briefly discusses how technology has influenced education. Special attention is paid to undergraduate teaching and medical training. However, other examples are included, such as changes in school education due to technology. As three-dimensional (3D) technology is the main focus of this doctoral study, its relationship with education, in particular with dental education, is examined separately.

2.5.2 TECHNOLOGY AND EDUCATION

Several authors believe that higher education will continue to change as technology advances (Garcia, 2012; Gumport and Chun, 1999; Duhaney, 2005). Altbach et al. (2009) in a report prepared for the UNESCO about the trends in higher education stated that in the 21st-century technology has drastically impacted on education. The following four areas are felt to have experienced the biggest changes:

"communication of knowledge", "distance learning", "publication of journals, books, and e-book", and "academic management".

As a consequence, it is likely that technology will continue to reshape education in the years to come. Indeed, some authors believe that technology has already provoked significant changes in education and that there is a need to embrace such changes (Collins and Halverson, 2010). Technology has a strong presence in today's classrooms, seminar rooms, libraries, laboratories and research units. We can even find technology inside students' pockets, in the form of mobile phones. But, how much of that change has been quantified?

Mayer (2002) argues that when multimedia resources are developed under a "technology-centred" lens rather than a "learner–centred" one, there is a lack of knowledge construction, and only memorisation occurs. The author argues that multimedia resources need to incorporate principles of educational theory and adult learning in their design. Considering the expansion of technology it is worthwhile asking if its use has a positive impact on education. Bransford et al. (2000) argue that the use of technology does not necessarily mean better learning, but they agree it can help to create effective learning environments. Interactive environments are examples of educational settings where the learner can experience and create his/her learning using technological resources.

Another argument that reflects changes in education due to technology relates to students' motivation. It has been shown that motivation affects the time a student is willing to use learning (Bransford et al., 2000). Evidence suggests that the use of technological resources enhances learners' motivation (Kadiyala and Crynes, 2000). In educational theory, motivation has a strong influence in driving deep learning (Arogundade, 2011; Ai-Lim Lee et al., 2010).

Clark (1994) claims that the use of media for education will not have an impact on learning unless the method underpinning the learning process has an educational basis. The author emphasises that cost-effectiveness needs to be assessed properly before deciding on the use of a media resource. He makes an analogy to simplify his beliefs explaining that the vehicle which transports food will have little effect on nutrition (Clark, 1983). However, it can be argued that the time used for transportation may have an effect on food freshness and therefore in nutrition. Kulik (1994) explored the use of technology for learning for school education. The author did a meta-analysis of 97 papers, and results suggested that technology enhanced the overall learning of students.

Access of information plays an important role in students' life, exemplified by the use of social media, computer technology resources and the Internet (Kirkwood and Price, 2005). So, if media impacts on knowledge delivery, then it has the potential to impact the learning process. Kirkwood and Price (2005) support the idea that technology by itself has a positive effect on learning, if only for the fact of it being novel. After studying the behaviour of a large population of students' paying attention to the use of technology for learning, they concluded that constructive alignment and instructional design were key elements to consider when determining how to deliver the information. Additionally, they felt it was important to state clearly the aims and objectives of the learning material. This reinforces the idea that the effect on learning is not exclusively due to technology access. However, this does not exclude the fact that technology has the potential to facilitate learning.

The Internet and computers have changed the way that information is stored and disseminated. Some authors believe that computer-based technologies offer the chance to promote learning and increase access to knowledge (Bransford et al., 2000). The use of the Internet has increased significantly in the UK in the last decade (ONS, 2012). Official reports from the Office of National Statistics (ONS) show that more than 80% of the population in the UK had direct access to the Internet in 2012. In another recent report, the ONS established that 99% of the population between 16-24 years use the internet regularly (ONS, 2013).This growth in the use of the Internet has accelerated the production of technological equipment, such as netbooks, tablets and smartphones which allow the user a constant and easy connection. These new devices result in the emergence of new applications, software and social media; resulting in changes in the way individuals interact and socialise (Wang and Wellman, 2010).

Prensky (2001) classified this new generation of technology consumers as “digital natives”. He defined a “digital native” as an individual who totally “speaks” the digital language. Under this category, he included mostly young people. On the other hand, he described those individuals who are familiar with the digital language but do not belong to the new generations as “digital immigrants”. In general terms, the author believes today’s students have changed, and education should adapt to their “new” way of thinking embracing the use of technology. Even though Prensky's (2001) views seem credible, there is no strong evidence to support such ideas. Bennett et al. (2008) reviewed the literature around the term "digital natives". Their work exposes lack of evidence supporting the need of an urgent change in education to satisfy new generations of students. Kennedy et al. (2008) asked first-year undergraduate students how much technology they used on a daily basis. Although the results revealed that most of the students used computers and the Internet, they did not use the technology entirely for educational purposes. Most students used these devices for emails, texts, and social communication, but very few used them for learning (Kennedy et al., 2008).

Shuell and Farber (2001) studied the perception of students towards the use of technology inside the classroom. They administered a questionnaire to 728 undergraduate and graduate students. The results revealed positive responses towards the use of technology. However, the data collected did not allow a deeper analysis of students' perceptions. Clarke et al. (2001) looked at the acquired learning among of 120 students undertaking a marketing course at Mid-Atlantic University, USA. They used a Likert scale to rate fourteen educational technology tools: chat room, electronic discussion group, FAQ page, instructor home page, Internet project, lab-only classes, online homework assignments, online lecture outlines, online readings, online syllabus, online student directory page, online student grade page, technology lectures and web site project. The results revealed that nine of those tools had a positive impact on the learning of students. The final recommendations of the authors were to include, whenever possible, an online syllabus, online team project, online home assignments, online lectures outlines and technology lectures. Among the limitations of the study, the authors recognised the homogeneity of the sample which only represented a tiny percentage of the student population.

Krentler and Willis-Flurry (2005) explored the effect on learning of online discussion. Results showed that students who participated more in the online class discussions (76%–100%) obtained significantly higher grades. The authors concluded that the use of technology enhanced learning, and they found the use of the Internet has a positive effect on the relationship between learning and the use of technology (Krentler and Willis-Flurry, 2005). However this could have been a result of brighter and more committed students taking part in the experience. Kadiyala and Crynes (2000) reviewed the literature in undergraduate engineering education. They concluded that technology enhanced learning when the learning objectives, the selected teaching technique and the technological resource had a good match. Garcia (2012) suggested that the expansion of the use of the Internet positively correlates with the growth of distance education in higher education (Garcia, 2012). Moreover, technology has made possible the emergence of virtual classrooms (Parker et al., 2011; Monahan et al., 2008).

Despite the evidence showing a positive link between learning and technology, some authors suggested a disconnection between the use of technology and education (Kennedy et al., 2008; Bennett et al., 2008). Moreover, some authors identified barriers when technology is used for educational purposes (Ertmer, 2005; Wright and Wilson, 2011; Baek et al., 2008). Ertmer (2005) looked at the reasons why teachers did not integrate technology into educational practice. His results indicated that academics did not get enough support for the use of technology. Baek et al. (2008) explored the reasons why teachers used technology in elementary and middle schools in South Korea. The results revealed that most of the time improving learning was not the main driver. On the contrary, stronger reasons to use technology were motivated by institutional policies or personal expectations that technology would make their job easier. Another finding was that newly qualified teachers are more prone to use these technologies compared to experienced tutors (Baek et al., 2008).

In higher education, Brill and Galloway (2007), investigated views of academics about the use of technology for education. Their study revealed that teachers used a range of technological resources such as overhead projectors, the video cassettes (VCR), slide projectors, the Internet, large screen video data displays and instructor computer workstations. The biggest barrier declared by academics was the lack of access to technological resources. Brill and Galloway's (2007) findings were similar to the results reported four years later by Wright and Wilson (2011). Wright and Wilson (2011) did a qualitative analysis exploring the most common barriers that stop teachers from using technology for teaching purposes. The authors concluded that lack of equipment was the most common reason.

In medical education, the idea that technology has the potential to enhance learning has also been mooted (Chodorow, 1996). A study carried out at the University of Liverpool two decades ago, revealed that 92% of medical students used computers and the Internet on a daily basis. However, only 25% of the participants used these technological resources inside the medical faculty (Mooney and Bligh, 1997). In a recent study, Trelease (2016) presented evidence of how technology, the use of computers and e-learning have become a reality for anatomical sciences, resulting in new opportunities and challenges for the educators. Moreover, the use of computers and the Internet has allowed the creation of virtual classrooms, computer-based assessment and computer-assisted learning (Ward et al., 2001). Vozenilek et al. (2004) proposed that technology has the potential to change the old fashioned "see one, do one, teach one". They suggested that with the use of technology students' can "see one, simulate many, do one proficiently and teach one". Nevertheless, evidence demonstrating the educational impact of these technologies is still required (Valcke and De Wever, 2006). Harden (2006) claimed that technology had impacted on two areas of postgraduate medical education –technology for simulation and the growth of e-learning.

2.5.3 e-LEARNING

Various authors have defined e-learning (Ellaway and Masters, 2008; Clark, 2002; Wagner et al., 2008; Govindasamy, 2001; Zhang et al., 2004) and there are general definitions such as: "e-learning is the use of the Internet for education" (Ellaway and Masters, 2008), as well as more detailed definitions for example, "e-learning is content and instructional methods delivered on a computer (whether on CD-ROM, the Internet, or an Intranet), and designed to build knowledge and skills related to individual or organisational goals." (Clark, 2002). Ruiz et al. (2006) claimed that e-learning relates to teaching that occurs remotely, using computers, the Internet or the web. Ellaway and Masters (2008) add that e-learning has to be flexible, engaging, student-centred, interactive, and collaborative. This holistic explanation permits a better understanding of e-learning; not just as a way of how to obtain information but as a complete learning methodology.

Among the advantages of e-learning are its flexibility (Childs et al., 2005), cost effectiveness, reusability, ease of disseminating the information and the fact that users can progress at their own pace (Zhang et al., 2004). However, to promote learning it needs to contain meaningful educational principles aligned with a student-centred approach (Clark, 2002). Otherwise, e-learning becomes meaningless. Evidence suggests that the use of e-learning can result in better assessment scores when compared to traditional methods, such as classroom-based teaching (Zhang et al., 2004). However, further evidence is required to determinate if e-learning technology facilitates the achievement of learning outcomes. A recent meta-analysis conducted by Lahti et al. (2014), explored the effect on knowledge, skills acquisition and students' attitudes toward the use of e-learning resources in nurse education. The results revealed limited evidence that technological tools are better than traditional methods. Regardless of the gap in the literature surrounding the educational efficiency of e-learning, technology has certainly impacted on education (European Commission, 2011).

2.5.4 m-LEARNING

Park (2011) defined mobile learning (m-learning) as: "the use of mobile or wireless devices for the purpose of learning while on the move". The concept of m-learning appeared in 1980 with the use of handheld computers. In the 90s, handheld computers become popular in higher education. With time, these devices evolved to digital PDAs (personal digital assistants) (Kukulska-Hulme et al., 2009). PDAs are small handheld devices able to store information. Kho and colleagues (2006) explored the literature assessing the impact of PDAs in medical education from 1993 to 2004. They showed that 70% of medical trainees in the United States used these devices for learning.

Communication and mobility are two main concepts in m-learning (Sharples et al., 2005). Sharples et al. (2005) believed that the social-constructive educational theory underpins m-learning, as the learner constructs knowledge based on collaboration and cooperation with other individuals. Vavoula (2005) looked at how adult learners learned during a two-week period. Participants were asked to record their learning habits. Fifteen individuals completed the task. The results revealed that 49% of the learning occurred outside their usual educational place. This study demonstrates that not all learning takes place within a formal environment. However, it is important to consider that the study used a small sample to make definitive conclusions.

With the advance of technology, mobile phones and portable tablets have become more accessible. A report conducted by Crabtree et al. (2003) revealed that 90% of young people and 75% of the general public in the UK have mobile phones. A survey carried out at the University of Texas revealed that personal computers, personal phones, and pen drives were the most common technological devices used by students and academics (Corbeil and Valdes-Corbeil, 2007).

Pegrum et al. (2013) claimed that mobile devices, such as iPads, have changed the way individuals search for information, communicate, socialise and learn. The authors explored how the iPad contributed to the learning and teaching of eight pre-service teachers. The research methods used were observation, interviews and focus groups. The results suggested that the device helps students to develop their learning and reflective practice even outside the campus. Three limitations were disclosed about the use of the tablet. The first was the restricted capacity for producing documents the iPad offered. The second was the long time needed to learn how to use the device. The last limitation discussed encountered negative attitude towards the use of the device demonstrated by two participants, mainly because they felt challenged by the technology and did not value the use of the device for learning. Despite the restrictions of the study, the authors concluded that iPads are valuable tools and aid students recall, consolidate and expand their knowledge, as well as enhance their reflective practice (Pegrum et al., 2013).

2.5.5 OTHER LEARNING METHODS AND TOOLS INFLUENCED BY TECHNOLOGY

Technology has influenced changes inside the classroom. An example is the use of Interactive Whiteboard (IWB) systems. Smith et al. (2005) reviewed the literature and concluded that students and teachers preferred the use of IWBs over traditional boards. However, it is still not possible to claim that learning is improved by the use of IWBs (Higgins et al., 2007). Nevertheless, this trend of incorporating IWBs in school classrooms is real thus it needs to be acknowledged.

In medical education, there is some evidence which suggests that plasma screens have a positive effect on learning. Price Kerfoot et al. (2005) observed 37 sessions of small group tutorials to explore the effect of the use of technological plasma screens and computers for learning. After each session, they asked teachers and students about their learning experiences of using these devices using a Likert scale. The results showed that instructors and learners saw a positive effect in the learning process when using these devices. Among the benefits perceived were: the multimedia capacity, the ease of access to information, the access speed of information.

Technology has also impacted on the traditional textbook. Electronic books (e-books) are digital books which can be displayed in different mediums such as computers, laptops, tablets, and phones. Recent evidence revealed a growth in the use and publication of e-books (Dewan, 2012). However, e-books and traditional printed books still do co-exist (van der Velde and Ernst, 2009).

Technology has also changed the traditional presentation method with a move from old fashion slides to PowerPoint, developed by Microsoft (Redmond, Washington, USA). PowerPoint is a computer-based software package which creates digital slides and is one of the most common methods used today for presentations. Moreover, Zhao (2007) stated that PowerPoint is one of the technological tools embedded in daily teaching. However, it took time for PowerPoint to become of the most commonly used presentations tools (Daniels, 1999), as users required instruction and induction sessions to learn how to use it properly (Zhao, 2007). PowerPoint has been used for more than two decades and the software has changed little during this period. However, Microsoft has added features and updates to improve the performance, the user interface, and its design. For example, the latest version allows the user to access, review, edit, analyse and present from their mobile devices (Microsoft, 2016).

Keynote is another presentation software developed by Apple Inc. (Cupertino, CA, USA). It was launched to the public in 2003 (Apple-Inc., 2003). Keynote is intuitive and easy to use, allowing the user to create attractive presentations. As well as Microsoft PowerPoint it uses slides where the user adds the information and graphics. Initially Keynote was operative only in MacOs devices; however, newer versions are fully compatible with Microsoft PowerPoint.

Prezi is another alternative for presentations. Prezi is an online free software package which can produce interactive and attractive presentations. Three young software developers from Budapest and San Francisco created Prezi in 2009. Today it has more than 160 million user accounts (“Prezi,” 2016). Chou et al. (2015) compared the use of PowerPoint and Prezi. The authors explored differences in formative and summative assessment performed by fifth-grade school students after attending different lecture presentations. The methodology included three treatment groups: one class was taught using PowerPoint, the second one used Prezi, and the control group used a traditional method with no visuals. The results revealed no difference between groups 1 and 2. However, both experimental groups performed better than the control group. These results contradict the thoughts of Kirkwood and Price (2005). The authors suggested that a novel technology would do better just because of being novel. However, PowerPoint and Prezi (the novel resource) preformed equally when compared.

Another example of technology inside the classroom is the use of audience response systems (ARS) also called clickers. ARS uses remote controls to collect instant replies from the audience. This method allows the tutor to pause, ask questions, usually using a multiple choice format, and analyse responses instantly. Kay and LeSage (2009) reviewed 67 papers published between 2000 and 2007 on the use of ARS for education. The collected evidence suggested that ARS had multiple advantages such as broader interaction and discussion among participants, better learning performance and higher quality of learning. Formative and normative assessment results were also enhanced by the use of ARS as well as opportunities for feedback. There were also higher levels of attention, participation, engagement and attendance by students. Challenges reported for academics when using ARS were about how to use the system and how to provide immediate feedback to the audience. Another negative aspect of the use of ARS was that some students did not like to be monitored or felt confused when the discussion involved multiple perspectives. However, the authors suggested the need for further research to determine the potential of ARSs for education (Kay and LeSage, 2009). Chien et al. (2016) conducted a meta-analysis of 72 peer-review papers most of them published after 2007 (63%). The evidence revealed that ARSs were valuable tools for instruction. The results suggested that its use produced better learning when compared to traditional lectures. Additionally, the use of clickers demonstrated higher engagement of students, better feedback provided, and that it served as an instance of reflection for students. The authors concluded that the use of ARSs had a positive effect on learning.

Podcasting is the name of an m-learning technique resulting from the combination of iPod and broadcasting. The technique allows students to access audios or videos containing their learning material previously uploaded to the Internet. To access the material the student needs to download the educational files and reproduce them in their mobile devices or computers. The technique benefits from simplifying the access to the information (Evans, 2008). Hew (2009) reviewed the use of podcasting and showed that despite the simplicity of the method and the approval of students it is still not extensively used. The author concluded that more evidence is needed to support the effectiveness of podcasting for teaching. Recent evidence suggests that podcasting has a positive effect on students' motivation (Bolliger et al., 2010). Further research has demonstrated that podcasting can be a valuable method to reinforce students' learning but not to the extent of replacing lectures (Schreiber et al., 2010).

It is important to realise that technology has moved faster than the publication of studies. Keeping updated with the literature is challenging yet important to understand the relationship of technology and education.

2.6 3D TECHNOLOGY

There is evidence to suggest that the first use of 3D dates from the year 280 B.C when Euclid of Greece produced a 3D effect by looking at an object from different angles. However, it was not until 1838 that the stereoscopic concept appeared when Charles Wheatstone used mirrors to obtain a stereoscopic image (Iizuka, 2006). The advance of technology increased the complexity and forms of 3D available. As a consequence, multiple displays and forms of 3D technology are commonly used - from 3D models to complex simulation systems.

3D technology is one of the central themes of this project. Therefore, it is important to review the terminology and definitions of the most relevant 3D technologies used for education. This review is limited to computer-generated 3D visuals.

Computer-generated 3D models are representations of a volumetric structure produced in a computer software. Yu et al. (2011) stated that "A 3D model represents a 3D object using a collection of points in the 3D space, connected by various geometric entities such as triangles, lines, curved surfaces, etc."

Several studies have explored the use of 3D models for medical education (Vernon and Peckham, 2002; Brenton et al., 2004; Nicholson et al., 2006; Hu et al., 2010; Cantin et al., 2015). Some of these studies are discussed below.

3D animations are among the learning resources available. Numerous authors have defined the term "animation" (Mayer and Moreno, 2002; Betrancourt, 2005; Vernon and Peckham, 2002). Mayer and Moreno (2002) said that the term animation refers to: *"A simulated motion picture depicting movement of drawn (or simulated) objects."* The authors suggest that there are three key features of this definition:

- Picture – animations are graphic representation

- Motion – animations illustrates movement
- Simulated – animations are simulated objects artificially created.

Vernon and Peckham (2002) defined animation as an object or image with the capacity of creating the illusion of movement. Regardless of the accuracy of these two definitions, they do not clarify if the animation was created with a computer or using a pen and paper. Betrancourt (2005) argues that the concept of computer animation is misunderstood. He collected some of these definitions and proposed the following one as an alternative: *"Computer animation refers to any application which generates a series of frames so that each frame appears as an alteration of the previous one, and where the sequence of frames is determined either by the designer or the user" (page 290).*

Therefore, 3D animations are computer generated animations using 3D digital models (Lasseter, 1987) collected in the form of a video. Many studies have argued that 3D animations are an appropriate educational resource (Cleeren et al., 2013; Prinz et al., 2005; Vernon and Peckham, 2002; Glittenberg and Binder, 2006).

The term "simulation" is widely used when it comes to 3D technology. In essence, a simulation is the *"imitation of a situation or a process"* (Oxford Dictionaries, 2016). In computer science, this replication requires the presence of a model, software or hardware to conduct the simulation process.

Several papers have explored the use of 3D computer generated simulators for medical education (e.g, Krange et al., 2012; Glittenberg and Binder, 2006). Similarly, there are studies which look at the use of 3D simulations for dental education (e.g, Quinn et al., 2003; Söderström et al., 2012; Weingärtner et al., 1998).

Virtual reality is an innovative resource that in some areas of knowledge can bridge the gap between theory and practice (Jenson and Forsyth, 2012). Virtual worlds are a combination of virtual computer reality and a chat environment (Dickey, 2003). The mixture of three key elements: 3D space, a visual representation of the user and the interactive chat produce the illusion of being immersed in a virtual world. Dickey (2003) reviewed the three most used virtual world programmes. One of the aims of the review was to present an overview of the implications for education of these three applications. The author provided evidence of the characteristics of these resources and their use for education. The clearest argument proposed that virtual environments could be used to enhance collaboration and distance learning. However, little was mentioned about how to apply and use them for education. Apparently, these practical aims were beyond the scope of the review. Thus, the author did not present any conclusions about the contribution of "virtual worlds" for education.

One of the latest types of 3D technology are Haptics. Minogue and Jones (2006) defined the term haptics as: "*the study of touch and the human interaction with the external environment through touch*." Haptics are a mixed technology that adds sensory sensation to the simulation system. Haptic technology provides the sensory and visual feedback allowing the user to manipulate objects using a 3D interface. In medical and dental education haptics have gained popularity mainly for training purposes. As a consequence, various papers have addressed the use of haptics for education (Yau et al., 2006; Yamaguchi et al., 2008; Konukseven et al., 2010; Sakellariou et al., 2009; Yoshida et al., 2011; Suebnukarn et al., 2009, 2010; Hanson, 2011; Gal et al., 2011).

The terminology surrounding the use of 3D for education can be confusing because it overlaps. For example, a 3D model may or may not be an animation, and it can also be part of a simulation system. A haptic device may have a virtual reality scenario which can be computer-based only or attached to a hardware that allows the simulation to occur.

Another issue relates to defining what it is real 3D. For example, one may question if a video (animation) using 3D models is real 3D if displayed on a flat screen. Or, does it need to be exhibited on a stereoscopic monitor to fit the 3D definition? To clarify this issue of terminology, the researcher sought advice from an expert. Professor Chris Rowland (personal communication), from the Duncan of Jordanstone College of Art and Design at the University of Dundee, explained that: *"For visualisation purposes, 3D elements should be able to move in Cartesian space along the X, Y, and Z axes and allow user interaction."* Within this thesis, the interactive component needs to be present when defining real 3D. Therefore, 3D resources displayed in a 2D format were not considered unless they were interactive and behaved in 3D.

Evidence suggest that when it comes to visualising 3D technology males and females performed differently (Hamilton, 1995; Linn and Petersen, 1985). Velez et al. (2005) observed gender differences in their sample when participants were asked to complete a computer-based visualisation test. Males outperformed females in the spatial-visualisation and spatial-orientation tasks. Hegarty et al. (2009) conducted a study assessing dental students' spatial ability using two different tests. Students from first and fourth-year participated, psychology students also took part in the study. The results revealed that male participants outperformed female participants in all the tests conducted. These findings led to the conclusion that spatial ability is affected by gender. While there is strong evidence suggesting that males perform better than females in tests such as the rotation ability, Newcombe and Stieff (2012) argue that there is no reason to believe that women or any subject lack of spatial ability as it is an ability that can be trained.

2.6.1 REPORTED ADVANTAGES AND DISADVANTAGES OF 3D SYSTEMS

Brenton et al. (2004) proposed that 3D models had several benefits for education. Among the advantages the authors mentioned was that 3D models can be accessed whenever needed as the models can be uploaded to the Internet to ensure a wider access. They suggested that 3D models can aid spatial ability training. They can also simplify the visualisation of different stages of a disease or structure (Brenton et al., 2007). Warrick and Funnell (1998) pointed out that 3D digital resources are easy to access and Vernon and Peckham (2002) suggested that 3D models are easy to share, they can be repeatedly used and do not decay in time. As 3D models can be used by students anywhere and as many times as required (Brenton et al., 2007), this resource can supplement activities such as formative assessment and self-learning sessions (Brenton et al., 2007; Warrick and Funnell, 1998).

Dias et al. (2011) reported “accessibility” as one strong advantage when using 3D digital technology for dental education. For example, the Internet permits direct access of the information from any computer as many times as are required (Dias et al., 2011). Similarly, Suman et al. (2010) stated that the Internet could facilitate students’ access to these resources from outside their school by using mobile devices or personal laptops. The reusability of 3D technology correlates positively with a cost reduction in the long-term, making it cost-effective to generate these resources (Vernon and Peckham, 2002).

When looking at the advantages and disadvantages of haptics the researcher recognised that their construction is complex and expensive. Among the report benefits of haptics is the possibility they can enhance self-learning manual skills thanks to the visual and tactile simulation they offer (Gal et al., 2011).

Chen et al. (2005) explored the relationship between “learning styles” and the use of 3D virtual reality environments. The results of the study revealed that, regardless of the student’s learning style, there was a positive effect in the achievement of those individuals who used the virtual reality environment. The results were even better when the student received instruction as well as the 3D material during the intervention. Individuals that had a traditional instruction based on lectures and reading materials obtained the lowest results. Despite the positive effect that the use of the simulation system offered, further evidence suggested that supervision, feedback, and guidance are needed when novice learners deal with these innovative systems (Wierinck et al., 2005).

The high cost of the construction of 3D models is one of the well-known disadvantages of these technological resources (Vernon and Peckham, 2002). Brenton et al. (2007) suggested that they can be expensive and time-consuming to generate, as their successful development demands special equipment. When it comes to the construction of a haptic simulator, again cost has been reported as the main issue (Gal et al., 2011; Hanson, 2011).

2.7 DENTAL EDUCATION AND TECHNOLOGY

2.7.1 DENTAL EDUCATIONAL TRENDS

Dental education has evolved over the last forty years. Table 2.2 shows the results of a literature review carried out by Pyle (2012).

Table 2.2: Systemic changes in educational models in dental education in the last forty years.

New Technique	Rationale/Impact
Comprehensive patient care	Coordinated care in the interest of the patient
Competency-based education	Setting mastery level educational expectations
Educational format: Small-group learning/simulation	Develop critical thinking and lifelong learners Foster deep learning Give students more responsibility for their learning
Economic models focusing on clinical education: Patient-centred care	High cost of clinical education model
Community models of clinical education: Federally Qualified Health Centres (FQHCs)	High cost of clinical education and need to address oral health needs of underserved populations
Reorganisation of curriculum: Tracks of themed curricula	Integration of basic and clinical sciences; introduction to science and technology

Extracted and adapted from Pyle, 2012.

Today's dental education is more inclined to promote a student-centred approach rather than to follow an old-fashioned teacher-centred model. The embracement of student-centred methodologies into the dental curricula began slowly in the late 1990s gaining more supporters by the year 2000 (Pyle, 2012).

When analysing changes in the curriculum, it seems that traditional methods have been replaced or reinforced by new technologies and the integration of basic science to practice (Pyle, 2012). For instruction, there are also noticeable changes, such as the use of small groups and a problem-based methodology. Fincham and Shuler (2001) revised the use of problem-based learning and confirmed the existence of a tendency to incorporate this method into the dental curricula. There is evidence of the usefulness of problem-based (PBL) or scenario-based learning (SBL) for dental education (Garvey et al., 2000; Rich et al., 2005). Moreover, some authors believe that PBL and SBL motivates students and aids them with the construction of their knowledge (Garvey et al., 2000; Rich et al., 2005).

Pyle (2012) stated that distance education and virtual reality simulation can improve learning. There are many studies that have explored the use of e-learning in dentistry (Brisbourne et al., 2002; Mattheos et al., 2008; Welsh et al., 2003; Schönwetter and Reynolds, 2013), and the use of virtual courses to enhance the curriculum (Bateman et al., 2015). Moreover, evidence suggests that dental students favour the use of e-learning technology (Reynolds et al., 2007). Schönwetter and Reynolds (2013) launched an online study to explore the use 39 web-based tools by thirteen European dental schools. Participants represented dental schools from nine European countries. The results revealed that currently dental schools used most of the e-learning materials mentioned in the survey with virtual reality and haptic devices being the most frequently used category, while the least popular were computer-based assessment tools. The main challenges found were the excessive time involved in the generation of the resources, difficulties in managing a correct use, and issues related with cost. The authors suggested the importance of recognising the existence of these technologies and the challenges surrounding their use for the education of future dentists (Schönwetter and Reynolds, 2013)

The use of technology has also influenced the dental clinical field. Shastry and Park (2013) mention the increased use of digital dental articulators for postgraduate orthodontics in the United States. Dental radiology has also experienced huge changes due to the advances of technology (Wenzel, 2002). Despite the existence of several types of technological resources for dental radiology and imaging (Benington et al., 2010; McNamara et al., 2011) evidence suggests that their use, especially in undergraduate education, is still uncommon (Parashar et al., 2012).

Several authors have noted the high costs involved in the training processes in dental education (Pyle et al., 2006; Pyle, 2012; McAllister et al., 2015). A recent report conducted by McAllister et al. (2015), revealed that dental education has become more costly due to the acquisition of new clinical technologies. Therefore, the study revealed that the use of technology for dental education has resulted in higher tuition fees.

2.8 3D TECHNOLOGY AND DENTAL EDUCATION

It is important to discuss the relationship between 3D technology and dental education. This section has two aims; to collect the evidence surrounding the use of 3D for dental education and to elucidate the impact that 3D has for dental education.

3D technology has become important for Dental Education, a fact that can be confirmed by the increasing numbers of publications available containing the terms 3D and dental education. For example, a search conducted in Scopus showed that there were three papers published about these two topics in the year 2000. From 2010 until 2015, 36 papers were published each year on average.

This review focused on papers published from the year 2000. For data collection, Scopus meta-base was used. The terms: “(3D OR three- dimensional) AND (dental OR dentistry) AND education” were searched. A secondary search was done using the terms “3D AND "dental education"”, “"three-dimensional" AND "dental education"” and “3D AND education AND dentistry”. The search also included terms such as “odontology”, “pedagogy” and “dimensional”. In total 441 papers were identified. The researcher applied the following criteria to limit the search:

- Papers with a clear focus on the use of 3D technology for dental education
- Manuscripts where 3D technology was developed or assessed
- Papers relating to resources in the form of 3D computer animation, simulation, virtual reality or haptics
- Articles or reviews published in academic journals

- Papers in English or Spanish

After removal of duplicate papers and application of the criteria, 31 papers were considered. The considered manuscripts aimed to reveal the current link between 3D technologies and dental education. To enhance the analysis, the researcher divided the data into categories based on the type of 3D technology used. These were: computer-based simulations or animations, haptics, virtual reality, image and radiology and clinical models.

Hu et al. (2009) used multimedia computer software containing 3D animations and simulations to compare two groups of students. One group used the software, and the other group had no access to computer instruction. The results revealed that students who had access to the 3D multimedia software obtained significantly better results in a written assessment. Also, they asked fewer questions to tutors during the training sessions and prepared a higher number of teeth. Finally, the authors concluded that the use of 3D multimedia software had a positive effect on dental education performance (Hu et al., 2009).

Tooth morphology is a subject extensively represented by 3D models. Usually, to develop the models scanning of real teeth is needed. Mitov et al. (2010) developed an e-learning platform for tooth morphology with interactive models. The user could zoom, rotate and access panoramic views of the 3D prototypes. The perception analysis of 36 students, suggested that Morpho-Dent could aid instruction and learning of tooth morphology.

Nagasawa et al. (2010) created a database containing fifty-five decayed teeth for the study of tooth morphology. The user could move arbitrarily and explore the 3D models extensively when using the software. However, the authors did not assess users' perception nor its usability for education. Similarly, Mowery et al. (2010) described and reviewed the development of an atlas containing 3D models, radiographs, photos, and videos.

Maggio et al. (2012) compared the use of 3D and 2D models as part of an e-learning module about tooth morphology. The study analysed the results of a written assessment of two groups. One cohort of students used the e-learning module while the other group used a traditional teaching method. Additionally, they explored the perceptions of students' who used the e-learning module. The results suggested that e-learning was a reliable method for learning tooth morphology which was mostly appreciated by students.

Researchers have explored student perception about the learning benefits of an atlas of tooth morphology for dental education (Wright and Hendricson, 2010; Salajan et al., 2015). Wright and Hendricson (2010) obtained negative results on a survey exploring dental students' perceptions of a Tooth Atlas containing 3D models. In their study, students received a DVD containing a tooth atlas to reinforce tooth morphology learning. As voluntary involvement was low, the authors offered incentives to encourage participation of students. Finally, a total of 128 (43%) students requested the DVD. The results revealed that students did not highly value the resource. Considering this information, the Dental School of Texas University decided not to include this atlas in their curricula. However, it is important to mention that the survey did not focus on the usefulness nor quality of the 3D models. It focused on the overall use of the resource. Also, the authors placed much emphasis on whether the students requested the DVD for installation, yet that does not necessarily mean that the participants used the resource.

Salajan et al. (2015) assessed students' perceptions using questionnaires. One hundred and seven first-year dental students from a Canadian university took part in the study. Participants had to rate and assess several aspects of a computer-based 3D digital atlas that was available during their semester. The statistical analysis and interpretation of the results suggested that students valued the use of the atlas mainly to prepare for exams and to learn tooth anatomy. On the downside, students raised some technical issues such as malfunctioning or difficulties when manipulating the resource. Finally, the authors conclude that the educational principles used in the resource enhanced the knowledge acquisition and exploration of tooth anatomy 3D visuals.

Qi et al. (2013) conducted a randomised control trial comparing the learning effectiveness of 3D learning resources compared to a 2D version. Ninety-five junior dental students from Wuhan University were randomly divided into three groups. One cohort received an online course which had 2D images, text and multimedia videos. The second group used a software containing 3D resources. This software allowed students to freely interact with the resource. The third group had access to the same software as the second group but the degree of interaction within the 3D components was restricted and guided. After the intervention, a multiple choice quiz assessed the learning effectiveness. Results revealed that students performed significantly better when they had access to the 3D resources with restrictions in the interactivity. Those students that used the 3D software with no restrictions obtained the lowest scores in the assessment.

3D technology computer-based software has also been used to inform patients about dental treatments options (Ammann et al., 2010). Consequently, the use of this technology is not limited to students' education as they have proved to have the potential to inform patients.

Other authors used 3D tools to standardise the evaluation process of cavity preparation (Hamil et al., 2014; Taylor et al., 2013). Sampaio-Fernandes et al. (2015) aimed to evaluate the correct preparation of an occlusal seat using 3D images of the preparations performed in acrylic teeth.

Other 3D packages described in the literature had clinical purposes. Kim et al. (2009) proposed a model using 3D technology to track tooth brushing movements. In their work, they described how the software was produced. However, they did not include testing or an assessment of the resource.

In the field of endodontics, Gao et al. (2009) proposed a computer-based 3D model to quantify tooth and root canal preparation. The authors highlight the potential of the model for educational purposes. However, the assessment of the resource was beyond the objectives of the paper. Overall, the study only looked at the presentation and development of the model. Similarly, de Boer et al. (2013) described a technique of how to develop 3D models of teeth. The procedure created models of teeth which could be observed in virtual haptic simulators for different purposes. However, no assessment of the models was included.

Vuchkova et al. (2011) looked at whether 3D technology had a positive effect when learning radiographic interpretations. Multiple-choice questions were used to measure students' learning. Fifty-nine students took part in the study. The results revealed significantly lower scores after using the 3D resources, indicating that 3D technology did not enhance the learning of radiographic interpretation. However, the outcome of the perception questionnaire showed enthusiastic responses from students toward the use of 3D technology. These results were surprising for the research team as they expected more positive results after the use of 3D technology. Nonetheless, the assessment method selected, were exclusively 2D panoramic radiographs and MCQs so that no alignment existed between the teaching objectives, the method of instruction and the assessment. Despite this weakness, it is interesting how positively students reacted to the 3D material. However, the authors suggested that it is important to recognise limitations and advantages of new instruction systems before embracing them into the curricula.

3D technology has been used in dental education for the creation of rapid prototyping. In brief, the prototyping techniques refer to the creation of solid objects from a computer based software (Chan et al., 2004). This technique is popular in the field of oral surgery, restorative dentistry, and orthodontics. However, its use has not been widely explored for educational purposes. Chan et al. (2004) used 3D technology to design a training cube for operative dentistry. However, the authors did no evaluation of its educational effectiveness. Soares et al. (2013) also used 3D prototypes with an educational purpose. They created a video of the 3D computational models to be used during the teaching session and gave the material to forty second-year dental students for testing. Then they collected the students' perceptions of the quality of the 3D prototypes and the video. There was a positive response towards the technique. However, the assessment tool was very short, and the authors did not conduct a statistical analysis of the data.

Virtual reality and haptics are mostly used for clinical training purposes in dental education. In the field of periodontics, there are digital packages combining 3D stereoscopic views and haptics. Steinberg et al. (2007) presented the PerioSim which simulated the periodontal probing procedure of novice dental students. The study included the development process and evaluation of the software, highlighting the sensory features offered. Marras et al. (2008) introduced a new haptic system addressing cavity preparation for endodontic accesses. The software and hardware simulated a virtual patient where the user could perform a simple cavity preparation. Feedback indicated that it was a complete and exciting package. However, no information was given on how students' perception was assessed. The images presented were of very low resolution making the simulation somewhat different from reality.

Pohlenz et al. (2010) explored students' perceptions of a haptic simulator. Participants were asked about: (a) the value of virtual reality as an additional educational modality, (b) the simulated force feedback, (c) the spatial 3D perception, (d) the resolution and (e) the integration of further pathologies. Results indicated that the simulator was well received and considered realistic enough by students for training purposes.

In the field of prosthodontics, haptic simulators have been used to assess clinical performance. A pilot conducted by Eve et al. (2014) assessed novice and expert dentists' performance when removing carious tissues using a haptic simulator. The comparative study demonstrated that experienced subjects were less conservative than junior dental students when drilling the simulated teeth. However, no evaluation of the tool was carried out.

Suebnukarn et al. (2014), concluded that the haptic simulator offered good content validity. They compared the access endodontic cavity preparation as performed by a group of novice, junior and expert dentists. Despite the positive results, it is important to bear in mind that the sample was small (n=34) and that these conclusions relate only to the specific software and hardware used in the experiment.

Suman et al. (2010) described the creation of a virtual learning environment for dental education. The paper explained the steps undertaken for the creation of the resource. Dias et al. (2011) discussed the development of virtual resources for dental education. Yamaguchi et al. (2012) described the developmental steps for the creation of a virtual face, including soft and hard tissues that served a virtual reality haptic resource. In none of these studies an evaluation was carried out.

Stereoscopic view, virtual reality and haptics can work in combination. In a study by Anderson et al. (2013) a detailed head and neck anatomy software was developed and validated by a multidisciplinary team. Funded by the NHS Education for Scotland, the software aimed to become the most detailed 3D virtual resource for head and neck anatomy in the world. The same research team used this same software for the presentation of a haptic virtual simulating dental anaesthesiology techniques. However, to date, there is no evidence of the usefulness or effectiveness of these resources for dental education.

Kikuchi et al. (2013) carried out an experimental randomised comparative study aimed to determine if the use of a virtual reality simulator enhanced clinical skills of students. The intervention had three groups. One group had access to the simulator and to a tutor’s feedback; the other had access only to the virtual simulator; while the third group had access to a traditional phantom head. Participants had to do a tooth preparation for a porcelain over metal crown (PMC). The results revealed that the groups that had access to the virtual simulator produced significantly better and faster preparations, with fewer errors than the control group. The findings lead to the conclusion that the use of a virtual reality simulator improved students’ performance when it came to PMC preparation (Kikuchi et al., 2013). Papadopoulos et al. (2013) presented a virtual reality computer-based software where dental students could simulate a paediatric consultation and clinical procedure. The resource aimed to reinforce knowledge about communication management with the dental paediatric patient. The authors conducted a comparative study to assess the usefulness of the resource. One hundred and three fourth-year dental students were divided into two groups. Fifty-two students had access to the virtual reality resource while the rest only had access to a written clinical scenario. After the intervention seven multiple choice questions were given to the students assessing knowledge in communication management. Additionally, a Likert scale questionnaire was given to the first group to explore students' perception of the resource. The findings demonstrated that the group who had access to the virtual reality software obtained significantly better results on all questions. While the perceptions questionnaire, revealed positive responses as students indicated that the resource was easy to use.

Of the thirty-one papers reviewed 16 presented new software or novel uses of 3D technology (Mitov et al., 2010; Nagasawa et al., 2010; Kim et al., 2009; Gao et al., 2009; Cantin et al., 2015; Steinberg et al., 2007; de Boer et al., 2013; Marras et al., 2008; Suman et al., 2010; Dias et al., 2011; Mowery et al., 2010; Salajan et al., 2015; Yamaguchi et al., 2012; Anderson et al., 2013, 2014; Ammann et al., 2010). Eight addressed students perception of used of 3D tools by means of Likert scales (Mitov et al., 2010; Maggio et al., 2012; Hamil et al., 2014; Soares et al., 2013; Vuchkova et al., 2011; Wright and Hendricson, 2010; Salajan et al., 2015; Papadopoulos et al., 2013). However, only six were comparative studies (Hu et al., 2009; Maggio et al., 2012; Qi et al., 2013; Vuchkova et al., 2011; Kikuchi et al., 2013; Papadopoulos et al., 2013). From these comparative studies, only one addressed the effectiveness of the 3D resources for education; a randomised control trial carried out by Qi et al. (2013). This seems to be the only study looking at the impact of learning using 3D resources in dentistry.

2.9 STUDIES EXPLORING THE USE OF 3D AND THEIR EFFECT IN LEARNING RESULTS

Tan et al. (2012) explored the efficacy of a computer-generated 3D laryngeal model for anatomy teaching compared to traditional 2D images. Forty junior doctors took part in the study. Results indicated that there was no statistical difference when using the 3D learning resource or the traditional method. However, participants reported that they preferred to use the 3D models for learning. These findings are similar to the ones obtained with the third-year students. Junior doctors are equivalent to third-year students in the sense that they are not novice learners as they have completed the basic medical training. This evidence indicates that mature students obtain mostly the same results whether using 3D technology or 2D images for learning.

On the other hand, Prinz et al. (2005) looked at the impact of 3D animations for understanding cataract and glaucoma surgery among 172 medical students. They randomised participants in two groups: 3D group (n=90), that had access to 3D animations and video sequences, and a control group (n=82), that saw two surgical videos. The outcomes showed that the 3D group performed significantly better than the control group in topographical understanding and theoretical understanding. The authors did not give the age or the degree of expertise of the individuals. However, it seems that they were novice learners. These results are aligned with those obtained with first-year dental students in the present study.

Tanagho et al. (2012) compared the impact of 2D and 3D visualisations simulating the performance of laparoscopic surgery. Thirty-three participants with varying laparoscopic expertise completed three procedures using the 2D and 3D tool. The degree of experience of the participants ranged from: expert n=3 (9.1%), intermediate n=5 (15.2%), novice n=23 (69.7%), unsure n=2 (6.1%). Participants were randomly divided into two groups: 2D or 3D. The results indicated that the 3D group preformed significantly faster over the three tasks, with fewer errors perceived in the peg translation skill. These results indicate that there was no statistical difference between “novice” and “expert/intermediate” participants. However, the sample of inexperienced subjects was almost three times bigger than the experts and intermediate cohort. The findings suggested that the 3D tool had a positive effect on training. However, no comparison between groups was conducted.

Two studies from dental education (Qi et al., 2013; Söderström et al., 2012) provide some evidence similar to the one obtained in the present intervention. Söderström et al. (2012) compared the use of two learning methods: a screen-based virtual reality radiology simulator and a PowerPoint presentation. The authors used a pre-test/post-test design where thirty-six participants were randomly assigned to either the simulation material or to the traditional teaching method. The assessment tool measured the proficiency of interpreting spatial relations in radiographs before and after the training session. The results revealed that the simulation group obtained significant improvements compared to the traditional method. In the Söderström et al. (2012) study, the target sample was fourth-semester dental students. Usually, at this stage of training, dental students are starting their training for the interpretation of radiographs, so this group could be considered novices. The outcome observed aligns with the results of the present study, suggesting that the use of 3D technology does have a positive effect on junior learners. Very similar findings were reported by Qi et al. (2013). The authors performed a randomised control group experiment with three groups. The results favoured the use of the 3D technology over the 2D method. The sample were junior dental students finishing their first year of training, who were novice learners.

2.10 CONCLUSION

The use in practice of educational theories and principles for adult learning have influenced the methods and strategies for education, moving from a teacher-centred approach to a student-centred one. Dental education has also experienced this shift, embracing methodologies for learning where the students play a more active role in the process.

Additionally, the use of technology has resulted in the development of new learning resources and methods. The arrival of social media, mobile devices, personal computers, clinical technologies and visual technologies have modified how and where education occurs. These technological resources allow students to access information easily, to re-use the learning materials, to study at a distance and to practise and reinforce concepts or techniques. While limitations still exist, mainly due to the costs involved in the acquisition of this technology, the trend indicates that dental education has also incorporated several technological resources to their training methods.

This review of the literature explored the use of 3D technology for dental education and aimed to disclose the current use of this technology and clarify if the use of 3D has a positive impact on dental education. Despite the significant amount of software and resources available there is little evidence about the educational impact of 3D technology. As a result, the researcher concludes that there is a need to explore in depth the educational impact of 3D models and simulations, as well as explore students' perceptions of the use of 3D technology.

3 IDENTIFYING AREAS OF NEED FOR THREE-DIMENSIONAL LEARNING RESOURCES IN DENTAL EDUCATION

3.1 INTRODUCTION

This first study identifies those areas within the dental curriculum that might benefit from the use of 3D technological resources. The results inform later chapters of this dissertation and provide justification for the construction of a 3D learning resource.

3.2 BACKGROUND

Mayer (2002) suggested that the developmental process of most of the technological teaching tools presented to date follow a "technology-centred" approach rather than a "learner-centred" one, resulting in a weak retention of learning. Therefore, having a "learner-centred" approach and considering students' needs when developing a new 3D learning animation/simulation, should help students learn better and favour their long-term retention.

As seen in Chapter 2 (literature review), several papers have discussed the development of new 3D learning resources. However, these studies did not clarify why the authors considered each topic.

Using experts opinion seems to be the standard approach to identifying student needs before the development of a new 3D technological resource (Nowinski et al., 2009; Rubin et al., 1998; Spallek et al., 2000; Nguyen and Wilson, 2009; Kobayashi et al., 2006; Henn et al., 2002; Dias et al., 2011). Another method used has been to evaluate the teaching difficulties of a certain topic (de Ribaupierre and Wilson, 2012). Others have considered the failure of traditional methods such as anatomic dissection of particular body areas when the area is too small or difficult to access (Hu et al., 2010). For others, the best method to inform the construction of the 3D resource was to consider perceived patients' needs (Kim et al., 2009). Larger scale projects have attempted to address students' needs by providing 3D resources for the entire dental curriculum (Salajan and Mount, 2008).

The collected evidence shows the involvement of different stakeholders to inform the construction of a new 3D technological resource. However, to date, students have had little participation in the process. Marsh et al. (2008) addressed this issue and conducted a survey at the Medical School of the University of Cincinnati, USA. The authors asked 36 students which areas of medicine needed a 3D digital resource to help them with their learning. All 36 students indicated that embryology was a topic that needed this type of resource. The authors attempt to satisfy students' needs aligns with a "learner-centred" approach. However, the sample was small, and the article provided few details of the methodology and composition of the survey.

Using a qualitative analysis, Henzi et al. (2005) explored dental students' perceptions of the strengths and weaknesses of the dental curricula. The results revealed that students were aware of their learning needs. Similarly, Divaris et al. (2008) identified the importance of students' participation in improving dental education. They suggested that it is important to consider students' opinions as part of the decision-making process for academic related matters (Divaris et al., 2008).

Considering that dental students are knowledgeable about their needs, why have they have received such little attention when developing new 3D learning resources? Apparently, expert opinion and practicalities took precedence over student opinions. One clear example is anatomy, a topic which has extensively used 3D animation and simulation (Mitov et al., 2010; Wright and Hendricson, 2010; Codd and Choudhury, 2011; Petersson et al., 2009; Battulga et al., 2012; Nguyen and Wilson, 2009; Henn et al., 2002; Nicholson et al., 2006; Salajan et al., 2009; Brown et al., 2012). The construction of anatomy resources has been justified by the reusability they offer which in the long term means they are less expensive than traditional methods (Hisley et al., 2008; Petersson et al., 2009; Jones, 1997). Additionally, the use of 3D anatomical animations or simulations has fewer ethical issues than cadaveric dissections (Nguyen and Wilson, 2009). These arguments were valid drivers in the construction of a digital resource. However, they did not consider students' needs and instead prioritise providers' needs.

Two main concepts framed this first study of this project. The first one relates to McKimm et al's. (2003) suggestion that: *"The first step in designing a web-based course is to identify the learners' needs…" (page 2).* The second one derives from the conclusions of Wagner et al. (2008) who looked at the importance of active participation of various stakeholders in the generation and subsequent success of an e-learning tool. They concluded that students, instructors and technology providers all had a valuable role in determining the successful generation of an educational software tool. Also, the published evidence has shown a gap in the literature when it comes to considering students' needs in the development of 3D digital resources for dental education.

3.3 AIMS AND RESEARCH QUESTION

This study sought to identify and prioritise the knowledge components and skills that would benefit from 3D virtual simulations in the context of dental education. The results informed the development of a learning resource containing 3D animations and simulations based on a "learner-centred" perspective.

The research questions for this study are:

- What are the knowledge components and skills that would benefit from being taught using a 3D virtual format?
- Which ones are perceived to have the greatest benefits for dental education?

3.4 METHODOLOGY

To address the research questions, it was considered necessary to explore the thoughts and experiences of potential users. This approach suggested the need for two combined methods to satisfy the qualitative and quantitative elements of the questions. Also, as experiences are different from person to person (Cohen et al., 2011) the mixed method approach selected maximises the chances of obtaining a complete data set and can also triangulate the findings (Begley, 1996). Mixed method methodology is well recognised (Schifferdecker and Reed, 2009; Tashakkori and Teddlie, 2003; Johnson and Onwuegbuzie, 2004), and has been reported in some 3D studies (Söderström et al., 2012; Bouta et al., 2012). Last and Fulbrook (2003, p.450) claimed *"By combining two methods it was anticipated that the rich data and high validity from the focus groups and interviews would complement the reliability and generalisability of the Delphi Study."*

Therefore, the researcher planned this study in two sections. The first section aimed to identify the knowledge components and skills that would benefit from a 3D format for teaching dental students. The second section sought to prioritise the topics previously revealed to produce a short list of priority topics. This list is used in later chapters of this research to inform the construction of a 3D digital resource.

3.4.1 ETHICAL CONSIDERATION FOR THE STUDY

The University of Dundee Research Ethics Committee granted ethical clearance (UREC: 13084 – Appendix 11). The study was developed under the framework of the World Medical Association Declaration of Helsinki (WMA, 2008) to satisfy high standards of ethics. The key ethical aspects considered were the recruitment process, the use of incentives, the data collection process and transparency of the researcher.

The recruitment process was unbiased as subjects agreed to take part voluntarily. The researcher had no prior or dependent relationship with them. Cohen et al. (2011) stated the importance of revealing the full identity of the researcher and the study background to the participants. An information sheet which contained comprehensive details about the study was given before participation Appendix 2. Also, a consent form was provided to participants who agreed to contribute

(Appendix 3). All participants knew they had the right to withdraw their participation at any time.

Incentives were used to attract participants. For the focus group section, students who agreed to take part were offered a certificate of participation awarded by the researcher and Dean of the Dundee Dental School. The intention was to recognise participants' consideration and time. In the second section, a monetary incentive was used to attract participants. Porter and Whitcomb (2003) analysed the effect of lottery incentive in students, and they found that a middle sized prize produced a slightly better response rate than larger or smaller prizes. With this in mind, two £50 Amazon vouchers were offered as incentives. Bias sampling is one of the potential problems produced by incentives (BERA, 2011). However, no concerns of bias sampling were perceived as all target students had the opportunity to participate.

Privacy, confidentiality and anonymity of data are ethical issues that were considered (BERA, 2011; WMA, 2008). The data collection and storage processes were explained to participants in the information sheet provided (Appendix 2). Data was collected keeping the identity of participants anonymous and only those directly involved in the study had access to it.

During the focus groups, the dilemma of the dual role (moderator-researcher) was addressed. Kitchener (1988) suggested that dual roles may lead to conflict and, in some cases result in exploitation of participants. To avoid exploiting participants, the moderator opted for a passive role, guiding an informal and relaxed conversation following a pre-set protocol.

3.5 SECTION 1: FOCUS GROUPS

3.5.1 METHOD

Focus groups are a widely used method for qualitative medical and social research (Kevern et al., 2001). This method offers the possibility of gathering innovative data via participants' interaction (Curtis and Redmond, 2007). Additionally, the exploratory purpose of the focus groups (Fern, 2001) served to collect participants' opinions toward which knowledge components (facts, procedures, concepts, and principles) and skills (cognitive and motor) could benefit from a 3D virtual format. Numerous studies have identified that data collected using focus groups is valuable in the construction of surveys (Wolff et al., 1993; Nassar-McMillan and Borders, 2002; Nichter et al., 2002). A recent example is Riquelme et al. (2013) who used focus groups to aid the construction of a Delphi questionnaire for medical education purposes.

Before determining the final structure of the focus group session, a pilot was conducted to inform the process.

3.5.2 PILOTING THE FOCUS GROUPS SESSIONS

Five dental postgraduate students from the University of Dundee were invited to participate in the pilot study to discuss which areas of dental education had a need of 3D digital resources. The following question was asked: "What are the knowledge components and skills that would benefit from being taught using a 3D virtual format?”.

The focus group was arranged following Krueger’s recommendations, to ensure that all sessions subsequent to the pilot study, followed a similar pattern, (Krueger (2009). The focus group was planned as a one-hour session led by the researcher. A colleague of the researcher helped with the data collection. The venue was setup within the Dundee Dental School facilities. The room furniture was arranged to facilitate conversation. For example, a small round table was installed to promote interaction among the participants.

The overall experience was good: people felt comfortable, and they engaged in the session immediately. The session lasted forty minutes and conversation was fluent. There was no need to modify the question as it was clearly understood. Knowledge components and skills appeared right away. Figure 3.1 contains the results of this pilot study. At the end of the session, answers were reviewed to confirm the validity of the data. Overall, feedback was positive; one participant suggested more structure during the session using elements of the dental curricula, so no topics were left out.

Number of participant: 5

Type of participants: postgraduate PhD students

Duration of the session: 40 minutes

Venue: 8th floor Hub 2

Results

Dental anatomy and tooth histology	Working length determination for RCT
Tooth growth and development	TMJ disorders
Biomechanics in orthodontics (tooth movement)	Glass ionomer setting
Mandible and maxilla growth and development	Amalgam setting
Space infections	Composite setting
Terminology of occlusion such as Benet angle, Benet movement, condylar guidance, anterior guide, excursive movements	Acid etching and dentine bonding
Mandibular fractures	Mechanism of action of antibiotics
Tooth preparation for crowns, onlay, inlay, ¾ crown	LeFort fractures
Gingival pockets formation	Oral pathology lesions
Nerve potential action	Cardiovascular system and nerve system
Chemistry of action of fluoride	Oral cancer development and progress
Ventricles of hart and how they work	Impact of alcohol and tobacco in oral mucosa
Cell mitosis and meiosis	Extractions technique movements
Mitochondria and Golgi complexes function	Suturing techniques
Serial extractions	Flap constructions
Inferior alveolar nerve block (how the needles penetrates and which tissues are related)	Fine needle aspiration
Local anaesthesia technics	Surgical removal of impacted teeth

Figure 3.1: Pilot focus group results

3.5.3 FOCUS GROUPS DESIGN

After the pilot study, the researcher developed a protocol, shown in Appendix 1. Forty minute sessions were planned and led by one moderator. After welcoming participants, the researcher briefly explained the aims of the project and checked if everyone read the information sheet provided (Appendix 2). Consent forms were given and completed before commencement (Appendix 3).

The target populations were dental students and academics from Dundee Dental School. The proposed participants were a sample from each undergraduate year and scholars from different dental specialities. The study excluded first-year dental students as their experience was considered too limited at the scheduled time of the sessions. Academics were approached directly, using a convenience sample, inviting them to participate in the focus group session, all major areas of the dental curriculum were addressed by the specialists that participated in the study.

The moderator and the scribe listed the items that participants considered would benefit from 3D digital resources. At the end of the session, the list was reviewed by the whole group to ensure that everyone felt the collected data reflected the discussion.

3.5.4 RESULTS OF THE FOCUS GROUPS

In total, the researcher conducted seven focus groups sessions; four with undergraduate students, one with postgraduate students and two with dental academics. On three occasions only one individual showed up; in those cases, the session was conducted as an interview following the same structure as the focus groups. Three individual interviews were carried out with students. In total 36 volunteers participated, generating a total of 198 items. Figures 3.2 and 3.3 are examples of the collected data.

Focus Group 1: Academics

Number of participants: 5

Background of knowledge of the academics: periodontology, endodontic, oral biology, prosthetics, microbiology / pathology

Length of the session: 30 minutes

Results

Tooth Anatomy - gross and microscopic anatomy
Masticatory process
TMJ anatomy
TMJ dysfunctions
Plaque and Biofilm formation
Block injection anaesthesia
Disease propagation through the body
Pocket formation and ulceration of the tissues due to plaque formation
Third molar extractions
Removal of large lesions such as cysts
Periradicular surgery
Surgical procedure of implants
Modelling of antibiotics action
Composite setting
Model explaining composite bonding
DNA double helix
Anatomy and Physiology of the Jaw
Clicking Joints
Molecular interaction of amino acids
Masticatory Muscles
Anatomy of the TMJ space

Figure 3.2: Example of the results of the focus group session

Focus Students 3rd year

Number of participants: 4 (3 females, 1 male)

Background of knowledge: 3th year students

Length of the session: 40 minutes

Results

Head and neck neuroanatomical: nerves, veins and arteries
Trigeminal nerve anatomy and landmarks
Muscles of the facial expression function
Eye muscles and functions
Muscles of the Jaw
Anaesthetic techniques
Plaque and biofilm formation
Caries formation
Tooth anatomy, micro and macroscopic
Embryology: how the face forms, the palate and tooth
Eukaryotes and prokaryotes interactive model
Cells structures and organelles e.g. Golgi complex interactive model
Protein synthesis
Gag reflex
Respiratory systems, macro and microscopic
Muscles involved in swallowing interactive model
Muscles involved in mastication, interactive model with different scenarios
Lymph nodes anatomic location
Salivary glands micro and macro anatomy including the physiology
TMJ intercalated disc movements
Peripheral and central nervous system
Path ways of pain
Model representing tooth response to different stimulus
Oral cavity innervation; soft and hard tissues
Local anaesthetics techniques
Cavity preparation, describing angles and instrumentation

Figure 3.3: Example of the results of the focus group session

Because the data collected in the pilot session was valid, the researcher decided to include the results of the pilot group session. The most frequently mentioned items are shown in Figure 3.4. After exclusion of repetitions, a list of ninety-seven items was constructed and can be seen in Appendix 4.

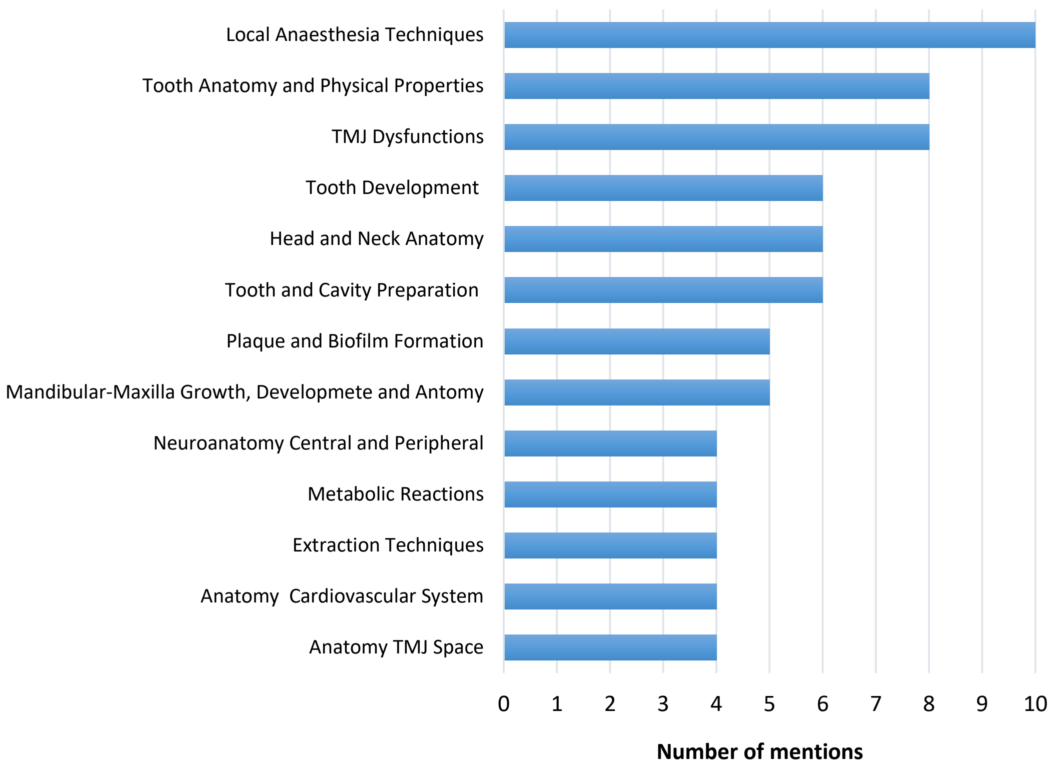


Figure 3.4: Most recurrent items from all the focus group and interview sessions

3.6 SECTION 2: THE MODIFIED DELPHI SURVEY

3.6.1 METHOD

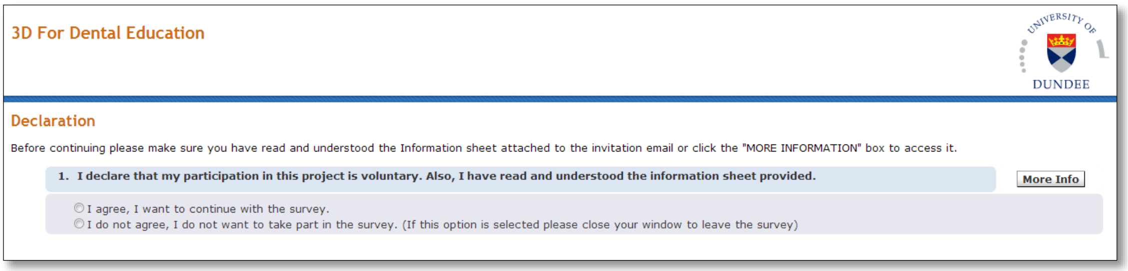
The Delphi technique is a research method widely used to reach consensus among a panel of experts (Hanson, 2011; Hardy et al., 2004). Hasson and Keeney (2011) undertook a comprehensive literature review and concluded that despite the high popularity of the Delphi technique it could have poor validity, reliability and rigour when its use is not well justified. In this study, the choice was to conduct a modified Delphi technique to determine which areas of dentistry have a need of new technological resources to aid dental education. The decision can be justified on the flexibility of the method (Powell, 2003) and the possibility it offers to prioritise items (Okoli and Pawlowski, 2004). Powell (2003) concluded that the Delphi technique could serve as a useful method to obtain information when there is a lack of empirical data. As the areas of need in dental education for a 3D digital resources had not been explored, it seemed appropriate to use this method.

3.6.2 SURVEY DESIGN

Online surveys have both advantages and disadvantages (Dykema et al., 2013). In the current study, the biggest concern was the potential low response rate. To tackle this issue Deutskens et al. (2004) suggested using short surveys, preferably using a written format, including reminders and monetary incentives.

To keep it simple for participants a five-point Likert rating scale was used. The survey included only one open question. For statistical purposes, the researcher included demographic items about gender and occupation. The University of Dundee had a licence to use Bristol Online Survey (BOS) for academic purposes and, therefore, this software was used to construct the survey. It is a user-friendly software ("Bristol Online Survey," 2013) which enables fast and straightforward data collection.

The final list of items obtained from the focus group results was arranged alphabetically from A to Z for the construction of the survey. The first page of the survey welcomed participants and was followed by an "agreement to participate" form. Figure 3.5 shows the declaration individuals needed to complete before accessing the survey.


3D For Dental Education

UNIVERSITY OF DUNDEE

Declaration

Before continuing please make sure you have read and understood the Information sheet attached to the invitation email or click the "MORE INFORMATION" box to access it.

1. I declare that my participation in this project is voluntary. Also, I have read and understood the information sheet provided.

More Info

I agree, I want to continue with the survey.

I do not agree, I do not want to take part in the survey. (If this option is selected please close your window to leave the survey)

Figure 3.5: Survey declaration.

During the survey participants were asked to rank each item based on their perceived need to have it as a virtual 3D format resource. The ranking scale went from 1 to 5 where 5 represented "Maximum Benefit" and 1 "Minimum Benefit". Figure 3.6 contains an extract of the final version of the survey; the complete version can be seen in Appendix 5.

3D For Dental Education

DUNDEE

Identifying areas of need of three-dimensional learning resources in dental education.

2. Please rate the following areas from 1 to 5 based on the benefit of a virtual 3D resource for dental education.

	Minimum benefit 1 2 3 4 5 Maximum benefit				
	1	2	3	4	5
a. Absorption of nutrients, from the gut and transport to the tissues					
b. Amalgam setting					
c. Anatomy of the Cardiovascular system					
d. Anatomy and Physiology of the heart including how the Ventricles work					
e. Anatomy of the larynx					
f. Anatomy of the TMJ space					
g. Anatomy of trigeminal nerve					
h. Basic Cellular anatomy and structures					
i. Biomechanics in orthodontics (tooth movement)					
j. Caries formation					
k. Caries removal including tactile feedback					
l. Cavernous sinus and cerebellum anatomy					
m. Cell mitosis and meiosis					

Figure 3.6: Extract of the online questionnaire.

3.6.2.1 PILOTING THE SURVEY

Ten postgraduate students from Dundee Dental School piloted the survey. Participation was voluntary, and they were asked to provide feedback. Ensuring clarity of items and establishing a completion time of ten minutes were key aims of the pilot process. The results revealed that some items were very similar. The list was re-assessed by three dental academics from the University of Dundee to ensure that the language was clear and precise. After revision, a final version of the survey was constructed and uploaded using the Bristol Online Survey server.

3.6.2.2 SAMPLE

The Delphi study targeted key stakeholders from the Scottish dental community. Final year undergraduate students, postgraduate, dental graduates and dental academics from the Universities of Dundee, Glasgow and Aberdeen were invited to take part. The researcher considered this group of people as "experts" as they had experience of most aspects of a dental career. As the researcher had close links with graduates, undergraduates, and academics from The Andes University in Chile they were also invited to participate. The researcher included this group applying a convenience sampling strategy. The benefit of including participants from Chile was to increase the number of participants and beneficiate from being a multi-site/cultural study.

Fourth and fifth-year dental students, academics and first-year dental graduates from the Universities of Glasgow, Aberdeen, Dundee and The Andes University (Chile) were invited to take part. Due to the difference in undergraduate training between Chile and Scotland, 6th-year students from The Andes University were also included. In Chilean dentistry, the bachelor degree is awarded at the end of the 5th year. In the 6th year, the student obtains a professional degree mandatory to work as a dentist. This is equivalent to the vocational training in the Scottish system.

3.6.2.3 LANGUAGE TRANSLATION

The survey was translated from English to Spanish by the researcher who is a native Spanish speaker. An experienced dental academic of the University of The Andes reviewed the translated list of items to ensure readability. The new list was not arranged in alphabetic order, to maintain the English version disposition of items, and to facilitate the data analysis process.

3.6.3 DATA COLLECTION PROCESS

A total of 1296 potential participants received the invitation email. The survey was open for five weeks. To increase the response rate, the researcher used two reminders; sent at week one and three after the initial distribution. Each University coordinated the dissemination of the survey, either by the administrator or the program director of each school. The survey was sent by email, containing the invitation letter and the information sheet. Additionally, a monetary incentive was used as discussed in the ethics section of this chapter. Data was collected automatically by the software when participants responded.

Collected data was statistical analysed using R-Studio software (www.rstudio.com Boston, MA, USA). R-Studio is a freeware statistical package that has gained popularity due to its powerful characteristics to perform statistics tests including non-parametric ones. Graphs and tables were constructed using Microsoft Excel software. The primary objective of this descriptive statistical analysis was to make comparisons among items rather than between participants and to obtain a ranked list of items.

The researcher conducted three analyses on the collected data:

- Ranking based on the frequency of participants indicating maximum benefit for each item.
- Gender comparison of those highly ranked items (summing up the scores 4 and 5 obtained in the survey).
- Comparison of graduate and undergraduate responses, for those highly ranked items (adding the 4 and 5 scores).

For the analyses ratings of 4 and 5 were categorised as "Beneficial" while items rated 1, 2 or 3 were categorised as "Non-beneficial". Only highly ranked items were used for statistical comparison using Fisher exact tests when exploring differences between gender and graduates versus non-graduates. Fisher exact test was used because some of the frequencies collected were very small or equal to zero.

3.6.4 RESULTS OF SURVEY

Two hundred and five responded to the survey, a 15.8% response rate (134 females and 71 males). Table 3.1 shows the items ranked in terms of greatest benefit. The results revealed that detailed anatomy of the temporomandibular joint, dental anaesthesiology, dental clinical skills techniques, dental occlusion and mandibular functioning were top priorities.

Table 3.1: Ranking regarding benefit for each item as a 3D learning resource for dental education

Item	Non-Beneficial	Beneficial
Anatomy of the TMJ space	2%	98%
Local anaesthesia techniques including the needle position, the tissues and how the needle passes through or close to.	8%	92%
Root canal treatment model representing happens inside the canal and how to determinate the working length	8%	92%
Anatomy of trigeminal nerve	10%	90%
Concepts in occlusion such as Bennett angle, Bennett movement, condylar guidance, anterior guide, excursive movements	10%	90%
TMJ dysfunction; including for example Clicking Temporomandibular Joints	11%	89%
Tooth and cavity preparation for crowns, onlays, inlays, ¾ crowns, endodontic access	13%	87%
Head and Neck anatomy	13%	87%
Surgical procedures for implants	13%	87%
Suturing techniques	14%	86%
Impacted tooth identification and extraction techniques	14%	86%
Extraction techniques: movements and force to extract the tooth	14%	86%
Occlusion functioning and types	14%	86%
Third molar extractions	15%	85%
Course of cranial nerves until the innervated tissues	19%	81%
Caries removal including tactile feedback	19%	81%

Space infections of the head and neck	19%	81%
Flap design	20%	80%
Mandibular and maxillary development, growth and anatomy	21%	79%
Masticatory muscles anatomy and physiology	21%	79%
Mandibular fracture	21%	79%
Normal movements of the jaw and pathological movement	21%	79%
Model showing most common errors and bad decision making for restorative dentistry (e.g. errors in prosthesis design, errors in crown preparation)	22%	78%
Removal of large lesions such as cysts	24%	76%
Use of elevators	25%	75%
Denture design - 3D model to design cobalt-chrome dentures	25%	75%
Le Fort fractures	25%	75%
Biomechanics in orthodontics (tooth movement)	25%	75%
Head and neck growth and development	27%	73%
Tooth anatomy and tooth physical properties	27%	73%
Periradicular surgery	27%	73%
Indirect vision practice model	28%	72%
Orthognathic surgery including for example, decompensation in orthognathic surgery	28%	72%
Facial imaging	28%	72%
Development of the dental arch	29%	71%
Instrumentation of deep pockets	31%	69%
Mastication process	32%	68%
Tooth development from beginning to eruption	33%	67%
Virtual dental articulator	33%	67%
Model in 3D of oral cancer development and progress	33%	67%
Most common oral pathology lesions	34%	66%
Caries formation	34%	66%
Embryological development of the palate	34%	66%
Dental instruments function, for example, the periodontal scaling instruments	35%	65%
Serial extractions	35%	65%
Dentine bonding	36%	64%
Virtual study models	37%	63%
Orthodontics - appliance design	37%	63%
Salivary glands physiology, micro and macro anatomy	37%	63%

Anatomy and Physiology of the heart including how the ventricles work	37%	63%
Process of enamel remineralisation using fluoride	38%	62%
Anatomy of the Cardiovascular system	38%	62%
Periodontal ligament structure	39%	61%
Anatomy of the larynx	39%	61%
Composite setting	40%	60%
Model to practice how to do wax build up	40%	60%
Pathology of Tooth development including for example amelogenesis imperfecta	41%	59%
Pocket formation and ulceration of the tissues due to plaque formation	42%	58%
Consequences of plaque over hard and soft tissues	43%	57%
Teeth chart to record full treatments	45%	55%
Model explaining composite bonding to enamel -- acid etching process	45%	55%
Impact of alcohol and tobacco in oral mucosa	46%	54%
Cavernous sinus and cerebellum anatomy	47%	53%
Plaque and Biofilm formation	47%	53%
Model representing the process of infections spread	50%	50%
Amalgam setting	51%	49%
Neuroanatomy central and peripheral	52%	48%
Model representing the gag reflex	55%	45%
Muscle contraction process	56%	44%
Fine needle aspiration	57%	43%
Pain pathways	57%	43%
Effect of drugs on the inflammatory process	57%	43%
Process of ossification and types of ossification	58%	42%
Eye anatomy including muscles and nerves	59%	41%
Circulatory system - blood flow in the body from lungs to tissues	59%	41%
Glass ionomer setting	60%	40%
Mechanisms of action of antibiotics	61%	39%
Basic Cellular anatomy and structures	63%	37%
Nerve action potentials	63%	37%
Disease propagation through the body	64%	36%
Ear anatomy model	68%	32%
Pharmacology - models of how drugs work in the tissues	69%	31%
Pathogenesis of diseases	69%	31%

Respiratory System model, including process of ventilation, perfusion	72%	28%
Drugs clearance methods	74%	26%
Kidney anatomy	75%	25%
DNA double helix	76%	24%
Physiology of the GI tract	76%	24%
Exchange of oxygen in the alveolus	76%	24%
Cell mitosis and meiosis	78%	22%
Metabolic reactions- pathways of chemical reactions represented as interactive models	78%	22%
Renal physiology	78%	22%
Hormonal cycles. From hormone production to their action	78%	22%
Absorption of nutrients, from the gut and transport to the tissues	79%	21%
Protein synthesis	83%	17%
Functions of Mitochondria and Golgi complexes	85%	15%
Molecular interaction of amino acids synthesis	86%	14%

When broken down by gender no statistical differences were found among highly ranked items (Figure 3.7).

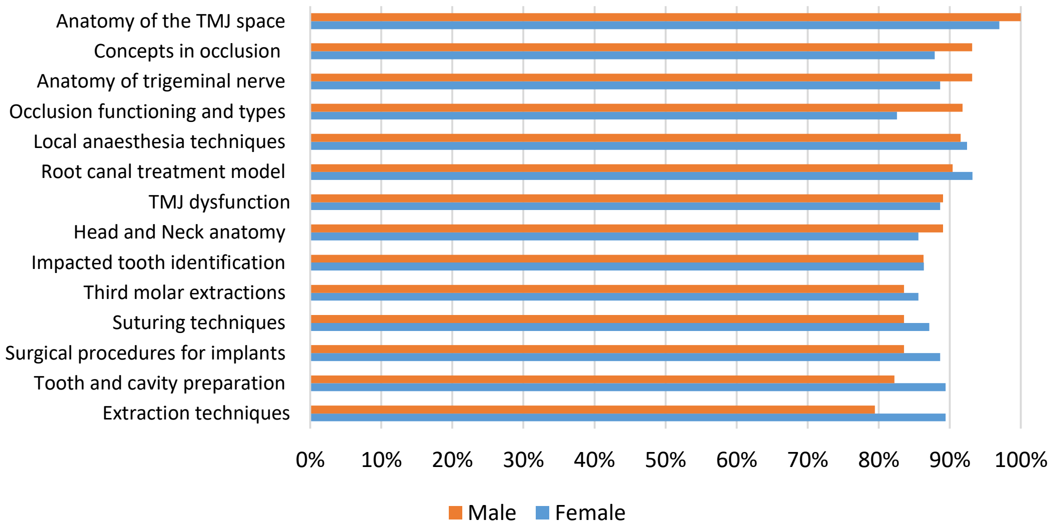


Figure 3.7: Gender comparison of perceived benefits for 3D resources

When comparing graduate dentists with undergraduate students only one of the highly ranked items: Head and Neck Growth and Development was significantly perceived as being more beneficial by academics than by dental students ($p<.05$) (Figure 3.8).

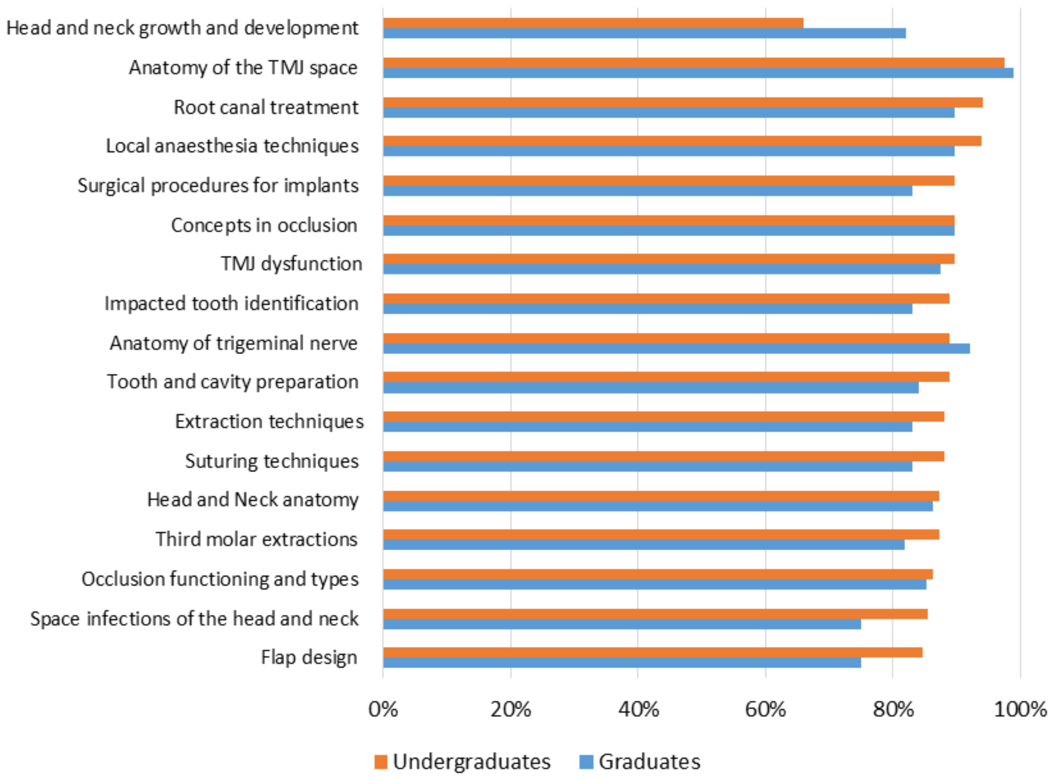


Figure 3.8: Graduates and undergraduates comparison of perceived benefits for 3D resources

3.6.4.1 OPEN QUESTION

Analysis of the open question revealed new areas to consider when developing a 3D e-learning resource; such as primary dentition and preclinical activities. Two participants indicated that all the areas in dentistry should have a 3D learning resource for education. Certainly, this would be the ideal scenario, considering that dentistry is a 3D professional practice. However, resources and technological access are still limited. Anatomy was one of the most commonly raised topics along with restorative dental techniques, surgical procedures and clinical skills. In general, the topics most cited were those related to clinical practice. All responses for the open question are detailed in Table 3.2. These elements have the potential to be considered in new studies similar to this one as they represent additional areas of need.

Table 3.2: Results of the open question of the survey

3D anatomy of both primary and permanent teeth in relation to what is seen on a radiograph
3D anatomy of the primary tooth pulp chamber in relation to class II cavity preparation to help visualise the proximity of the pulp to the restoration and the loss of proximal box to place a restoration on
3D images of anatomical structures e.g. pt. with a post-fracture for problem-solving, 3D virtual resource showing how that post would be retrieved
3D model, over time, showing the consequences of early extraction of primary teeth, balancing and compensating extractions and also the optimal timing for extraction of first permanent molars would be useful
3D visualisation of primary teeth pulp chambers for teaching about pulp therapy.
Accidents and complication of respiratory ways
All topic seen in pre-clinics
Bone grafting procedures e.g. block bone graft from the ramus for implant placement
Cannulation
Caries progression and patterns (bottle caries) in primary teeth.
Carving amalgam fillings
CBCT ability to explore sections and identify different anatomy.
Clinical techniques- step by step
Correct impression making techniques for different materials
Dealing with a locked jaw (How to unlock)
Dealing with internal and external pus (How to drain)
Dental restoration design. (CAD-CAM)
Developmental Biology
Diagnosis and treatment planning of worn dentition
Electro-surgery
Embryology developmental topics
Everything
Extirpating pulp
Face bow registration
How to write a prescription
Interview techniques for vocational training

Intraoral examination, what to look for, where to look, what is normal etc.
Oral cancer treatment- visualisation of reconstructive flaps, grafts, and obturators
Paediatrics procedures e.g. pulpotomy, Hall technique.
Physiology
Positioning for procedures depending on the area treated (extractions, perio, etc.).
Possibly denture provision stages/ lab work rather than students completing a year in lab setting
Sinus Lifting
Some way of introducing first years into treating interactive patients.

3.7 DISCUSSION

The aim of this study was to justify the selection of a topic for the future construction of a 3D learning resource based on dental students and academic dentists' perceptions.

The focus group results revealed that many areas of the dental curricula have a perceived need for the integration of 3D educational resources. In the United Kingdom (UK) the General Dental Council (GDC) regulates the dental curricula (GDC, 2015). Thus, the researcher considered it appropriate and representative to select participants from only one dental school for the first section of this study. The results included items from all the dental curricula from basic science concepts such as, "Cell mitosis and meiosis" to complex clinical skills such as "Surgical removal of impacted teeth". In total, ninety-seven items were identified which informed the construction of the modified Delphi survey. Overall, the researcher considered it positive to obtain items representing the complete dental curricula as this would not restrict the survey and provide plenty of options to the participants.

From the results of the survey, it was observed that topics that ranked highly are key subjects within Dentistry. The findings reveal that "Anatomy of the temporomandibular joint" was the highest ranked item with other areas relating to the anatomy of the head and neck also being ranked highly. These results are consistent with the importance that other studies have placed on the construction of resources covering anatomical structures (Brenton et al., 2004; Henn et al., 2002; Hu et al., 2010; Grimstead et al., 2007). Despite the existence of many resources for anatomy (Lewis et al., 2013), this study has identified a need for specific anatomical resources relevant to dentistry. One of the reasons underpinning these results might be that currently available models lack sufficient details to satisfy users' needs (Lewis et al., 2013).

Other highly ranked items were "Root canal treatment" and "Cavity preparation"; both relevant clinical skills that dental students need to be competent in at the time of graduation. Dentistry is a hands-on profession. Thus, it is not surprising that many of the items contained in this study have a strong relationship with clinical procedures and skills. Murray et al. (1999) found similar results in a study which asked new graduates about possible improvements for undergraduate curricula. Participants indicated that less emphasis should be placed on topics related to basic science, and more should be given to applied dental skills. However, it could be argued that first, second and third-year student groups were not included in the present study which could bias the results in favour of basic science topics encountered in dentistry. These groups were not included because respondents of the modified Delphi needed to be "experts" and be knowledgeable with all elements of the survey. It is important to emphasise that second and third-year students did contribute to the composition of the questionnaire incorporating elements of basic science. It would be interesting though to explore in future research the need for 3D dimensional resources per year of study.

“Dental anaesthetics techniques” was another highly ranked item. Anaesthetics techniques are complicated to learn and require a good anatomical knowledge and practical skills. In many aspects, its teaching is controversial, as in some schools, the first local anaesthetic injection performed by a student is given to a classmate (Brand et al., 2008) or a human cadaver (Jenkins and Spackman, 1995). Both of these practices are not free of ethical issues. It has been reported that dental anaesthesiology education varies across many universities (Brand et al., 2008) due to its complexity. The operator needs to control many factors, thus having a 3D aid to build-up confidence seems appropriate.

Spatial ability has been related to the capacity to manipulate 3D objects (Vandenberg and Kuse, 1978). The literature is inconclusive when comparing males’ and females’ 3D spatial ability. Some authors believe there is no difference between gender (Newcombe and Stieff, 2012), while others support the idea that this ability is better in males than females (Vandenberg and Kuse, 1978). The results from the present study revealed that there were no differences based on gender in the way participants ranked the items.

Academics perceive there to be a higher benefit of a 3D learning resource for head and neck growth and development than students. It might be that teaching this topic with the use of 2D images or diagrams is complicated or that graduates’ higher expertise makes them appreciate the benefit of this subject. However, the literature review showed no evidence to support these assumptions.

Interestingly, all groups indicated that the top priority item was “Anatomy of the temporomandibular joint”. The importance of the temporomandibular joint (TMJ) is crucial for dentistry as it is the basis of occlusion and functioning of the masticatory system. Therefore, it has been suggested that a proper understanding of the TMJ is mandatory before investigating the disorders affecting the joint (Okeson, 2013). Many authors find both teaching and learning about TMJ disorders challenging (Ash, 2007; Türp et al., 2008; Stockstill et al., 2011). This is further compounded by the lack of consistency in basic terminology surrounding the topic (Jasinevicius et al., 2000; Stockstill et al., 2011).

Statistical analysis revealed no difference in the way graduates and undergraduates perceived benefits of 3D for dental education. However, “Extractions of third molars” was almost significant, but still non-significant. The GDC determined that undergraduates should assess and correctly refer third molars (GDC, 2015), but not perform the extraction. Ideally, specialised surgeons should conduct third molars extractions, a fact recognised by dental students (Jarosz et al., 2011). However, some evidence suggests that newly qualified dentists would have liked to have training to perform that skill during their undergraduate education (Murray et al., 1999; Patel et al., 2006).

More females than males participated in both sections of this study. In total 92 females took part, compared to 54 males. This tendency was also observed in recent work done by Macluskey et al. (2012) across UK dental students which shows that more women are choosing dentistry as a career path (McKay and Quiñonez, 2012; Neumann, 2004; Gross and Schäfer, 2011). Therefore, the results of the questionnaire may be reflecting this tendency. Making formal conclusions about gender response would require specific data collection which was beyond the scope of this study.

One of the limitations of this study was the response rate. In the literature low participation within research is well known (Scott et al., 2011). In the present study, despite using proven techniques to increase participation, the response rate was 15.8%. Regardless of the response rate, some authors consider that the size of a sample is of greater importance (Nulty, 2008). Moreover, results of the 205 respondents who completed the questionnaire showed clearly the perceived benefit of each item for the participating subjects. The timing of the survey or participants "being too busy" are reasons for low response rates (Fenton-O'Creevy, 1998). To increase participation the researcher sent multiple reminders and gave several opportunities to participants to complete the survey. The layout of the questionnaire and the number of items could potentially discourage participation.

Despite the recognised limitations, this study reveals a need for 3D virtual resources in dentistry and points out the way forward in terms of a better long term education for dentists. It constitutes a valuable starting point for further studies related to the construction of 3D digital based learning resources.

3.8 CONCLUSIONS

Efforts need to be made to improve the facilitation of learning of the dental student. The topics which are perceived to have a greater benefit from being taught using a 3D virtual format are: detailed anatomy of the temporomandibular joint, dental anaesthesiology, dental clinical skills techniques, dental occlusion and mandibular functioning. In general, the need for 3D learning resources does not vary with gender or level of experience.

4 THE SOFTWARE SELECTION

4.1 INTRODUCTION

This chapter describes the selection of the most suitable software for the development of the required e-learning resource. The first section presents a feasibility study which compares various options of e-learning authoring packages. The second section provides information about the selected software, including evidence for its use in education.

4.2 SECTION 1: FEASIBILITY STUDY

4.2.1 AIM

To choose the most appropriate software for the development of the e-learning resource.

4.2.2 METHOD

The seven-step decision-making model created at the University of Massachusetts, Dartmouth was used (UMassDartmouth, 2015). This model describes analytically a decision-making process in a simple way and has a direct relationship with academic matters. However, few modifications were done to fit the purpose of this study. To inform the decision taken in Step 5 an analysis of the Strengths, Weaknesses, Opportunities and Threats (SWOT) was included. Figure 4.1 shows the seven-step model.

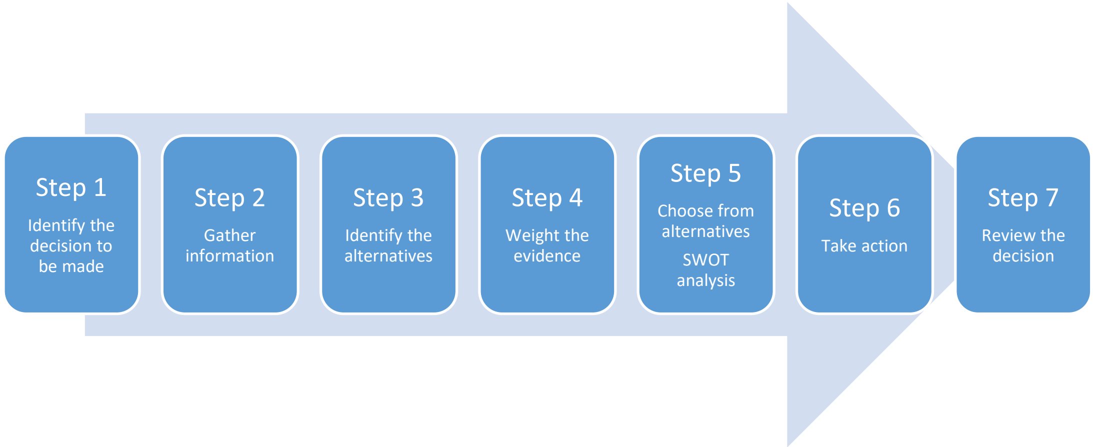


Figure 4.1 Decision-making process model

*Extract and modified from http://www.umassd.edu/fycm/decisionmaking/process/

4.2.3 THE ANALYSIS

STEP ONE: IDENTIFY THE PROBLEM

The main objective of this section was to identify an authoring software that allowed the incorporation of 3D digital interactive models into an e-learning resource. Additionally, the authoring package needed to be simple to use and fit the limitations in terms of the cost of this study. The research question that drove this section was: What is the most suitable software for the creation of an e-learning resource able to display 3D interactive models considering the limitation of this study?

STEP TWO: GATHERING INFORMATION

Gathering information was mainly achieved through Internet research, targeting keywords such as “software”, “e-learning”, “authoring”, “3D interactive model” and “e-books”. Searches used the following statements:

- “Best software to create an e-learning resource.”
- “Top ten authoring tools for e-learning.”

- “Best authoring tool for e-learning 3D interactive models.”
- “E-book authoring software that includes interactive 3D.”
- “Best authoring software that accepts 3D models.”

The search resulted in an extensive list of software and authoring tools that are currently available, each with different strengths and capabilities. Some used different operative systems and devices depending on the specifications of the software. The most common packages found were: Articulate Storyline, Adobe Captivate, Lectora Inspire, iSpring, Easy Generation, Smart builder, Brainshark, Adapt Learning, Camtasia Studio 8, Hot Lava, iBooks Author and Unity.

STEP THREE: IDENTIFYING ALTERNATIVES

As the Internet search resulted in many options, advice was sought from the medical artist at Dundee Dental School (M. R. Roughley personal communication). This opinion was of value because of two main reasons: first, he is an expert in the field, and secondly he agreed to develop the 3D models for this resource. After receiving his opinion, a short list of alternatives was presented and discussed in a meeting with the study team. Two factors were used as criteria for selecting possible software: 1) whether the medical artist was familiar with the programs and 2) whether the authoring packages were available at the Dundee Dental School.

Considering the options and the expert opinion, a short list was generated of the most suitable software for this stage:

- Adobe Captivate (Adobe System, Software Ltd. San Jose CA, USA)

- Articulate Storyline (Articulate Global, Inc. New York, USA)
- iBooks Author (Apple Inc. Cupertino, CA, USA)

STEP FOUR: WEIGHTING THE EVIDENCE

In this step, the aim was to prioritise the information and establish appropriate criteria that would inform the next stages of the process. The factors affecting the decision were considered, and the ideal parameters for the software were determined. The purpose of the study, as well as the limitations, were considered. Figure 3.2 shows the parameters.

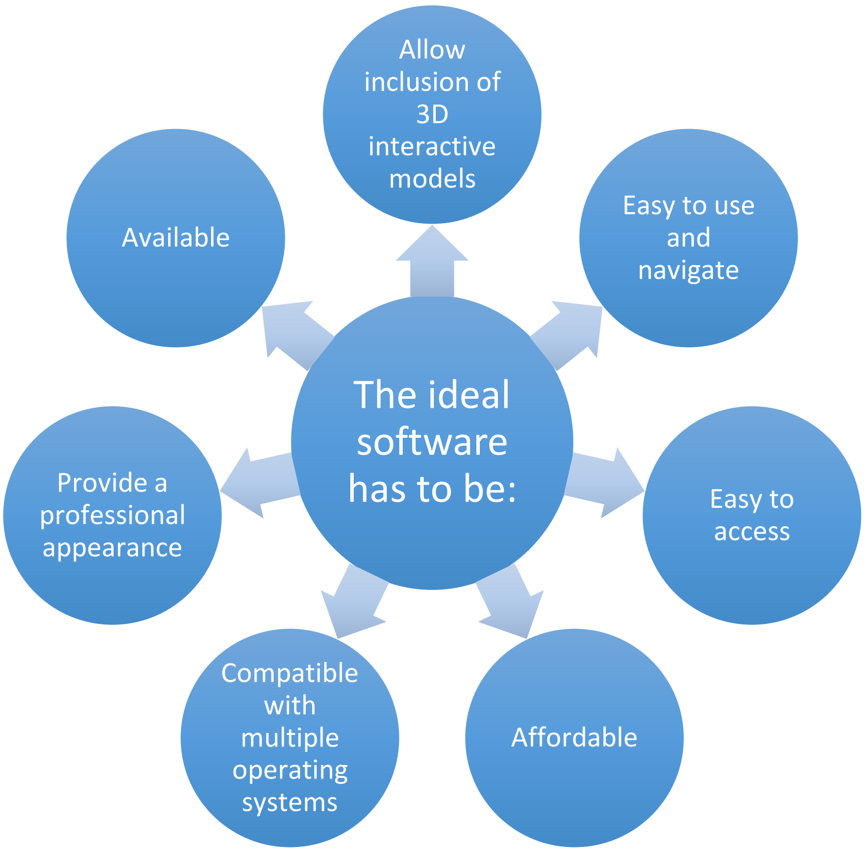


Figure 4.2: Parameters of the ideal software

PARAMETERS OF THE IDEAL SOFTWARE

a) ALLOW INCLUSION OF 3D INTERACTIVE MODELS

Enabling the inclusion of 3D interactive models was the most important factor considered at this stage as the resource was going to be used to assess the educational impact of 3D learning resources. Likewise, the package had to permit the users to have full control over the model, allowing them to fully interact with the 3D element when displayed in the resource. This characteristic was important to avoid restricting the interactive capabilities of the 3D model.

b) EASE OF USE

Any health professional regardless of how experienced with e-learning should be able to use and manage the authoring package. Help was sought from a qualified medical artist to generate the 3D content and 3D modelling, as experience and medical art skills are required.

c) EASE OF ACCESS

"Access" refers to how a new user acquires the software e.g. via a subscription, purchase of hardware or downloading it directly from the Internet. One condition was specified; the access to the authoring package should not limit the creation of new e-learning resources.

d) AFFORDABILITY

Ideally, the authoring package should be free or have a very low purchase cost. Subscriptions were not considered as they usually have a finite allowance of time resulting in further costs for the user.

e) Compatibility with multiple operating systems

The most suitable software should ease the dissemination process by being compatible with Windows, MacOs and Android operating systems.

f) Appearance

While not essential for the content display and the experimental purpose of this study, appearance was considered important as an attractive product can encourage engagement with the resource. It should include multiple visuals, a simple navigation and a professional design.

g) Permanent availability

It is important that the authoring tool to be available over a lengthy period of time. It was felt that the software should belong to a well-established company, to ensure that long-term projects were not be affected by a discontinuity or by changes to the package. Being available permanently enhances the possibility of producing similar new e-learning resources in the future.

STEP FIVE: CHOOSING FROM THE ALTERNATIVES

Three software packages were compared using the seven criteria explained above. Three members of the project team rated each criterion on a 1 to 5 scale using expert judgment, with 1 being lowest. Table 4.1 exhibits the criteria and scores obtained for the three selected software packages. The scores were summed up and iBooks Author obtained the highest score. Therefore, it was selected as the best alternative.

Table 4.1: Comparison of three authoring packages.

Criterion	Captivate	Storyline	iBooks Author
Inclusion of 3D interactive models	3	3	5
Ease of use	4	3	5
Ease of access	2	2	5
Affordability	2	1	5
Compatibility with multiple operating systems	5	3	0
Appearance	5	5	5
Availability	5	5	5
Total	26	22	30

SWOT ANALYSIS

In addition, a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis was carried out to confirm if iBooks Author was a good option to use. The SWOT analysis method is mainly used in business to evaluate internal and external issues that may or may not affect business planning (Pickton and Wright, 1998). Despite the existence of limitations inherent in the method, SWOT analysis has been useful in various areas of medical education (Gordon et al., 2000). Pickton and Wright (1998) suggest that SWOT analysis should be a group activity, using assessors with different sets of expertise. Hence, three members of the research team (principal researcher, medical artist and one of the supervisors) took part in a thirty minutes session to conduct the SWOT analysis and determine if the iBooks Author met the requirements for this project. Results of the analysis can be seen in Table 4.2.

Table 4.1 SWOT analysis for iBooks Author

Strengths	• Easy to use • Free to download • Very intuitive • No need for e-learning expert for content entry • Accept interactive 3D models allowing full interactivity to the user • Allows to provide feedback to students in the questions • Final product has a professional appearance • Can be exported easily and therefore shared • Very easy to duplicate (feature needed to create a second version of the software with 2D content)
Weaknesses	• The authoring tool works only with Apple MacOS computers and the iBook read on MacOS devices. • No possibility to insert files larger than 20 megabytes
Opportunities	• Allows for easy creation of a look professional e-learning material
Threats	• The fact that it is only suitable for MacOS restricts the dissemination of the iBook

The SWOT analysis confirmed the original decision. The main reasons were: that it accepts 3D interactive models that the students could use on a tablet with no restrictions in its interactivity, its ease of use and the free access to the package. The results showed that the system was only compatible with MacOS and Apple technology. However, this was not an issue as the Dundee Dental School has iPads that students can use and access. Moreover, it is very important to highlight that the central aim of this doctoral project was not to determine the best authoring tool available but to explore the impact of 3D interactive models compared with the use of 2D images.

STEPS SIX AND SEVEN: TAKE ACTION AND REVIEW DECISION

The choice of using iBooks Author and iBooks was re-assessed with the complete research team and everyone agreed on the decision.

4.3 SECTION 2: iBOOKS FOR EDUCATION

4.3.1 WHAT ARE iBOOKS AND iBOOKS AUTHOR?

Payne et al. (2012) defined iBooks as a “highly interactive multimedia e-book”. Apple Inc. created iBooks and launched the application in conjunction with iPads in January 2010. In 2012, Apple Inc. launched an application called iBooks Author that allowed the creation of high-quality iBooks by any user regardless their e-learning experience (“iBooks Author,” 2012). Payne et al. (2012) presented the perceived benefits and drawbacks of iBooks from a medical educator author perspective. Among the benefits, are the simplicity of the authoring process, the portability of the produced learning material and ease of distribution of the iBook. The biggest limitation is that iBooks can only be used in Apple devices which are costly (Payne et al., 2012). Despite their simplicity of use few studies have assessed their usability and efficiency for learning purposes. Three studies have explored the users’ perception of iBooks (Thomas et al., 2013; Baena-Extremera and Granero-Gallegos, 2013; Fenwick Jr et al., 2013). First, Thomas et al. (2013) asked 27 first-year students their thoughts about iBooks after watching a video displaying iBooks’ features. Ninety-four percent of responses revealed a positive attitude from students toward the use of iBooks for learning. However, they were not offered a “hands-on” opportunity to explore the tool. Baena-Extremera and Granero-Gallegos (2013) sent a questionnaire to 375 secondary school students and eleven academics. They showed an iBook with a projection system during lectures and offered students the chance to have a hands-on experience in groups. Students positively valued its use for education. Moreover, they considered the method highly efficient, novel, interesting and exciting. However, academics had some reservations about the efficiency of the use of iBooks (Baena-Extremera and Granero-Gallegos, 2013). Fenwick Jr et al. (2013) surveyed eight computer science students after using an iBook during their academic semester. The results revealed that students valued certain specifications of the iBook, such as its easiness of use, the videos and the search tools. Another section of the study compared the semester performance of those who used the iBook with another ten students who were given an interactive PDF instead. The results indicated that those students that had the iBook outperformed those ones who had access to an interactive PDF. However, no strong conclusions can be suggested from this study as little information on the methodology was presented, and the sample was very small. In the field of engineering, Chew et al. (2013), compared iBooks and PowerPoint lectures based on the following parameters: layout of content, interactivity, ease of use, functionality, level of interest, integration of learning tools and accessibility to additional content. Twenty-four participants were asked to compare the two resources. Results showed a clear superiority of iBooks over PowerPoint in all parameters analysed. Twenty-three participants stated that iBooks enhanced their learning experience.

4.4 CONCLUSIONS

This chapter has detailed the options appraisal process for selecting the most appropriate software for developing an e-learning resource. Results suggest that producing an iBook using iBooks Author was the best option. It is important to highlight that this study did not attempt to identify the best authoring tool available in the market.

Evidence found in the educational literature about iBooks and iBooks Author revealed that iBooks have the potential to positively affect the learning experience of users.

5 INSTRUCTIONAL DESIGN FOR THE DUNDEE IBOOKS

5.1 INTRODUCTION

To understand the design and authoring process of the e-learning tools required for this study, principles underpinning its development were explored to ensure rigour and quality. Race (2005) claimed that the authoring process of e-learning is complex, in some cases even harder than face-to-face teaching.

This chapter begins by defining what "reusable learning objects" are, followed by a review of the main principals related to e-learning. The next section discusses the twelve principles used for the construction of the iBooks. The last part of this chapter explains the instructional design method selected for the authoring process of the tools using evidence encountered in the literature.

5.2 THE REUSABLE LEARNING OBJECT

In computer science, the concept of Learning Object (LO) is widely used. The Institute of Electrical and Electronics Engineers (IEEE) suggests that: *"A learning object is defined as any entity -digital or non-digital- that may be used for learning, education or training"* (IEEE, 2002). However, this definition has been criticised for being too broad (Friesen, 2004).

Emphasising the reusability of an LO, the definition of "reusable learning object" (RLO) is also found. Defining what an RLO has been considered not a straight forward task, as it is unclear with regard to pedagogy, values, and roles (Friesen, 2004). CISCO (San Jose, CA. USA), a highly recognised IT company, provides a more precise definition, explaining that LOs have to have a learning objective; use metadata in different forms or disparate sources of data and information; have a content and; allow practice and assessment. Accordingly, they defined LOs as *"Ideally, a learning object is based on a single learning or performance objective, built from a collection of static or interactive content and instructional practice activities. Any learning object can be "tested" through assessments that measure the learning or performance objective and are either positioned with the learning object or collected as an assessment group"* (CISCO, 2003).

IMS Global Learning Consortium Inc. is a global non-profit member organisation created in 1995, devoted to creating standards for the growth and impact of learning technology. IMS has defined a learning object as "*Any reproducible and addressable digital or non-digital resource used to perform learning activities or support activities."* (IMS Global Learning Consortium, 2003b).

In simpler words, Windle et al. (2007) present the definition given by the UK-based Centre for Excellence in Teaching and Learning in RLOs (RLO-CETL) which stated that learning objects are: *"Web-based interactive chunks of e-learning designed to explain a stand-alone learning objective."*.

From the definitions presented above, it can be observed that a learning object demands to have a learning objective as the main element of the e-learning resource. Taking this into account, the researcher considered a complete iBook as one LO composed of multiple elements which contribute to the same learning objective.

5.3 PRINCIPLES FOR INSTRUCTIONAL DESIGN OF E-LEARNING REUSABLE LEARNING OBJECTS

In the literature there are several guides, books and papers covering good practice for the creation of e-learning resources (Bristol and Zerwekh, 2011; Haythornthwaite and Andrews, 2011; Clark and Mayer, 2011; Herrington et al., 2010; Ko and Rossen, 2010; Curry and Smith, 2005; Gordon et al., 2013; Mayer, 2002; Race, 2005). The IMS Global Learning Consortium (2003b) suggest that the instructional design method depends on the learning objectives, the learning activities, the learning context and the learning environment. Additionally, it has been stated that each instructional design method has its individual pedagogical principles as proposed by the designer, to satisfy the desired learning objectives (IMS Global Learning Consortium, 2003b). As a consequence, the literature contains a variety of pedagogic principles for instructional design (Gordon et al., 2013; Bristol and Zerwekh, 2011; Clark and Mayer, 2011; Boyle, 2003; Mayer, 2002; Herrington et al., 2009; Clark, 2002; Betrancourt, 2005; Newlin and Wang, 2002). Considering the abundance of information about instructional design the following section is restricted to the most relevant principles for e-learning.

Mayer (2002) suggested nine principles for the appropriate design of multimedia learning objects (Table 5.1).

Table 5.1: Nine multimedia principles proposed by Mayer (2002), adaptation of the original.

Principle	Explanation
Multimedia principle	Better transfer when a message contains words and pictures rather than words alone.
Spatial contiguity principle	Better transfer when printed words are placed near rather than far from corresponding pictures
Temporal contiguity principle	Better transfer when corresponding narration and animation are presented simultaneously rather than successively.
Coherence principle	Better transfer when irrelevant words, pictures, and sounds are excluded rather than included.
Modality principle	Better transfer from animation and narration than from animation and on-screen text.
Redundancy principle	Better transfer from animation and narration than from animation, narration, and on-screen text.
Pre-training principle	Better transfer when training on components precedes rather than follows a message.
Signalling principle	Better transfer when the narration is signalled rather than non-signalled.
Personalization principle	Better transfer when words are in conversational style rather than formal style.

Six of the principles proposed by Mayer (2002) were also described by Clark (2002) to enhance learning (Table 5.2).

Table 5.2: Six principles for effective e-learning proposed by Clark (2002)

Principle	Action
The multimedia principle	Adding graphics to words can improve learning.
The contiguity principle	Placing text near graphics improves learning.
The modality principle	Explaining graphics with audio improves learning.
The redundancy principle	Explaining graphics with audio and redundant text can hurt learning.
The coherence principle	Using gratuitous visuals, text, and sounds can hurt learning.
The personalization principle	Use a conversational tone and pedagogical agents to increase learning.

In the field of engineering, Boyle (2003) suggested the following principles for the design of LOs: cohesion, de-couple, and coherence. He explains cohesion as the need for one educational element to have a clear educational goal. The de-couple principle states that each learning object should stand by itself and be independent of another learning object. The coherence principle states that the content should be coherent and have pedagogical value (Boyle, 2003).

Betrancourt (2005) proposed five principles to enhance learning based on the cognitive load theory framework in relation to interactivity and the use of animations. These principles refer specifically to instructions for effective animations used for e-learning. As the iBooks contained animations and simulations, it was appropriate to include these principles in this section. Table 5.3 summarises the five principles.

Table 5.3: Principles for animations used in e-learning by Betrancourt (2005)

Principle	Explanation
Apprehension principle	The animation should be as simple as possible to facilitate comprehension by the learner. The author suggests that realism should be avoided if it does not contribute to the learning purpose.
Congruence principle	The animation can be altered from reality if this will help the student to grasp a concept.
Interactivity principle	For better learning students should be able to control the animations at their own pace.
Attention-guiding principle	Including guides in the animations, for example in the form of arrows and colours, will enhance learning.
Flexibility principle	The animation should have different points of activation for different learners.

Considering that iBooks are part of the mobile learning (m-learning) trend, the researcher looked at principles for m-learning suggested in the literature. Herrington et al. (2009) proposed eleven principles underpinning the authoring process for effective m-learning (Table 5.4).

Table 5.4: Principles and strategies for instructional design of m-learning by Herrington et al. (2009)

Principle	Strategy
Real world relevance	Use mobile learning in authentic contexts
Mobile contexts	Use mobile learning in contexts where learners are mobile
Explore	Provide time for exploration of mobile technologies
Blended	Blend mobile and non-mobile technologies
Whenever	Use mobile learning spontaneously
Wherever	Use mobile learning in non-traditional learning spaces
Whomsoever	Use mobile learning both individually and collaboratively
Affordances	Exploit the affordances of mobile technologies
Personalise	Employ the learners' own mobile devices
Mediation	Use mobile learning to mediate knowledge construction
Produse	Use mobile learning to produce and consume knowledge

Elias (2011) compared different principles for online learning and m-learning instructional design. He recommended seven principles for use in m-learning (Table 5.5).

Table 5.5: Principles and recommendation for m-learning suggested by Elias (2011)

Principle	Recommendation
Equitable use	Deliver content in the simplest possible format Use cloud computing file storage and sharing sites
Flexible use	Package content in small chunks Consider unconventional assignment options Leave it to learners to illustrate and animate courses
Simple and intuitive	Keep code simple Use open-source software
Tolerance for error	Scaffold and support situated learning methods
Low physical and technical effort	Use available SMS readers and other mobile-specific assistive technologies
Community of learners and support	Encourage multiple methods of communication Group learners according to technological access and/or preferences
Instructional climate	Push regular reminders, quizzes and questions to students Pull in learner-generated content

Van Merriënboer and Sweller (2010) proposed fifteen principles and strategies based on the cognitive load theory. Gordon et al. (2013) took ten of those principles and adapted them for an effective e-learning authoring process based on the aforementioned educational theory (Table 5.6).

Table 5.6: Principles and strategies for e-learning instructional design based on cognitive load theory by Gordon et al. (2013)

Principle	Strategy
Split-attention principle	Integration of materials coming from different sources of multimedia or given multiple times
Modality principle	It is more effective to use spoken words to describe an image (unimodal) than to display an image with text (multimodal)
Goal-free principle	Use goal-free tasks that provide learners with a non-specific goal
Worked-example principle	Use worked examples that provide a full solution, rather than asking learners to find a solution independengly
Completion principle	Use completion tasks that provide a partial answer that student's must finish
Redundancy principle	If one source of information can fully explain an issue to learners, then do not use other sources
Variability principle	Use information, cases or activities that illustrate variability to help to learn, such as different patient characteristics
Contextual-interference principle	Randomly order activities, rather than artificially placing them in blocks
Self-explanation principle	Self-explanation principle suggests giving detailed worked examples that prompt learners to explain new learning; showing them a video with information and then asking them to explain what they see
Expertise-reversal effect	This is seen when learning methods that worked at the start of instruction become ineffective as expertise increases, so expertise must be taken into account

The information presented above demonstrates that a correct instructional design process demands clarity, simplicity and flexibility for the outcome. However, repetitive information or excessive use of multi-media seems to damage the learning process instead of reinforcing it. Having a sound learning objective aligned with a precise number of multi-media seems to be the most important factor to consider. Overall the resource needs to provide users with a proper interaction using adequate language and guidance.

Another set of principles for e-learning are the ones proposed by the learning object attribute metric (LOAM) suggested by Windle et al. (2007). The LOAM tool is a scoring system proposed by Windle and colleagues used to assess the pedagogical attributes of a learning object (Figure 5.1). These principles were the ones selected for the creation of the iBooks. The main reason for this decision was that the LOAM tool has a very comprehensive approach. In addition, this method was designed to analyse the pedagogical attributes of reusable learning objects using a categorical scale. Windle's et al. (2007) work was important to the researcher because it allowed performing a simple assessment of the resource requirements. The analysis of the attributes is carried out by using twelve characteristics, each with its scoring criteria. Experts validated this tool using evidence provided in publications of the IMS Global Learning Consortium (2003a). Additionally, the choice of using Windle's (2007) work is supported by the fact that Payne et al. (2012) successfully used some of these attributes to explore the instructional design process for iBooks. Payne et.al's (2012) work demonstrates the simplicity of using these scoring criteria.

IMS Learning Design Framework		
Environment (%)	**Roles (%)**	**Activity (%)**
Text	Recipient of information	MCQ
Audio	Navigator	Answer Selection
Images	Active participant	Drag and drop
Animation	Contributor	Text entering
Video	Self-assessor	Image selection
Interactive elements	Problem solver	Image manipulation

Learning Object Pedagogical Attributes											
Inter-activity	Objective	Integration	Context	Richness	Pre-requisites	Support	Feedback	Self-direction	Navigation	Assess-ment	Alignment
1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5	5	5

Figure 5.1: LOAM scoring tool.

5.4 THE TWELVE PRINCIPLES FOR THE INSTRUCTIONAL DESIGN OF THE DUNDEE IBOOKS

5.4.1 INTERACTIVITY

Moreno and Mayer (2007) defined “interactivity” as the responsiveness towards the learner’s actions along the learning activity. The authors proposed the existence of five types of interactivities for multimedia learning: dialoguing, controlling, manipulating, searching and navigating interactivity. The iBook uses four of the five types of interactivities suggested by Moreno and Mayer (2007) only excluding the dialoguing interactivity which is not possible to achieve with iBooks Author. In the iBook the user can control, manipulate, search and navigate information throughout the resource. The use of interactive features has the potential to aid the cognitive process. However, the abuse or misuse of these elements can have a negative effect on learning (Moreno and Mayer, 2007). Thus, it is important to have a pedagogic argument behind the choice of any interactive element. Another interactive feature of the iBooks, is the tactile experience offered by the touchscreen of the iPad which according to Payne et al. (2012) allows students to engage actively. Windle et al. (2007) suggested that if more than 50%

of the reusable learning objects are interactive, then the resource is considered highly interactive. Therefore, in principle, the iBook should be as interactive as possible to engage students in their learning, carefully applying the coherence principles (exclusion of irrelevant images, words and animations) suggested by Mayers (2002) and avoiding the redundancy principle (explaining graphics only with audio instead of audio and text) highlighted by Clark (2002).

5.4.2 OBJECTIVE

According to Windle et al. (2007), well-structured reusable learning objects need clear learning objectives. In education, establishing sound learning objectives is the first step in constructive alignment (Biggs, 2002). Having appropriate learning objectives facilitates the construction of any learning activity, determining the direction and intentions of the learning resource. Knowles et al. (2015) explains that it is important that the learner knows why, what and how it is going to be learned. Therefore, the iBook should have clearly stated learning objectives adequate for the content.

5.4.3 INTEGRATION

Windle et al. (2007) explained “Integration” as the number of multi-media included in the learning resource. This attribute is scored higher when the reusable learning object (RLO) has multiple types of media. iBooks Author application allows the use of multi-media in the forms of galleries, videos, interactive 3D models, and interactive images. The use of these media connected with the correct text, allows a proper manipulation of the iBook fulfilling the integration attribute (Payne et al., 2012). The iBook should be a multi-media tool, making sure that multi-media are properly integrated.

5.4.4 CONTEXT

The “context” attribute scorers high in Windle’s (2007) attribute metric when the RLO is not exclusively about a determinate subject. However, the Dundee iBooks have a specific topic which directs the instructional design. As a consequence, the structure of the iBook depends on the subject. Hence, the iBooks were divided into chapters, sections and units depending on the subject. The iBook structure should be dependent on the context determined by the topic.

5.4.5 MEDIA RICHNESS

This attribute addresses the quality of multimedia elements including the contiguity principle. Giving contiguity to the content is crucial as it has been suggested that visuals, words or even pop-ups should be close together to maintain their educational relevance (Clark and Mayer, 2011). Evidence exploring eye tracking movements suggests that the closer the graphic and written information are, better the integration of the material by the reader (Holsanova et al., 2009). Repetition of information should be avoided when designing an e-learning space as it may generate an overload of the working memory. This precaution complies with the redundancy principle proposed by Mayer (2002). Evidence suggests that non-redundant material helps to achieve better retention by the learner, while excessive material provokes an overload of visual channels (Jamet and Le Bohec, 2007).

Clark and Mayer (2011) recommend that e-learning should contain multiple media elements to deliver the information. Additionally, when the centre of attention is an animation, the authors suggest that if using words, the best modality to use is speech rather than written text. Moreover, evidence suggests that informal speech is better than formal (Clark and Mayer, 2011; Kartal, 2010). The reason is explained in the framework of the personalisation principle which proposes that polite, but simple language achieves better learning (Clark and Mayer, 2011). A study conducted with 89 students in Turkey compared the use of neutral-formal, personalised informal and personalised formal language in a short multimedia presentation. Results revealed better scores when a personalised language was used rather than formal (Kartal, 2010).

Considering this information, media resources should be of high quality without affecting the pedagogical attributes, and they should keep a semi-personalised informal language.

5.4.6 PRE-REQUISITE

Windle et al. (2007) defined “pre-requisite” as the previous knowledge a user had to have before using a learning object. The learning object scored better when the learner did not require previous knowledge to use the tool. However, the iBooks created for this study are meant for dental students, so the language was content related and demanded a certain degree of pre-required knowledge. Nevertheless, to make the tool accessible to novice students, simple language was used as suggested by Curry and Smith (2005). Overall, the iBook needed to be easy to use and to provide sound information.

5.4.7 SUPPORT

This attribute is related to the level of instruction and support that the learner has while using the RLO. A high score in the LOAM represents adaptable instructions and support depending on the needs of the user. However, a lower score indicates the learning object had no instruction nor support included. In the case of the iBooks, the instruction is provided at the beginning of the resource using explicative icons. Simplicity and intuitive flow are fundamental principles recognised by Elias (2011) for m-learning.

5.4.8 FEEDBACK

Feedback is a fundamental principle of adult learning (Kaufman, 2003). Evidence suggests that it has a major role for e-learning (Hattie and Gan, 2011). Research findings indicate that feedback provided in an informative way is more efficient than when presented in a corrective manner (Moreno, 2004). Therefore, explaining the reason why a response is correct or wrong is of greater value to the learner allowing him/her to integrate knowledge, and it helps learners with processing information (Hattie and Gan, 2011). Additionally, Cook et al. (2010) suggested that the use of feedback has a positive effect on the acquisition of the learning outcomes.

In Windle's (2007) attribute tool, feedback is considered better when it can adapt to the learner's needs. Achieving this level of feedback is not possible with iBooks Author. However, as feedback is so important, the first iBook had corrective and/or explanatory feedback in the quiz section.

5.4.9 SELF-DIRECTION

"Self-direction" is important for the use of interactive technology (Murphy et al., 2004). Knowles et al. (2015) also believe that self-direction is a fundamental principle of effective adult learning; therefore, the Dundee iBooks were planned as a self-directed learning tool. Effective learners are capable of directing their learning process (Kaufman, 2003). Metaphorically speaking, an adult learner can be compared to a snowball, which might need help to roll at the beginning but once it reaches a slope, it becomes independent, self-directed and grows adding just the amount of snow it needs. This example aligns with the constructivist's theory for learning which states that knowledge is constructed based on experiences and interaction with the environment (Murphy, 1997). When the user has full control on how to use the reusable learning object, the resource is classified with a high capacity of self-direction (Windle et al., 2007). In the case of the iBooks, the index allows the user to jump, search and scroll different sections of the iBook, giving him/her control on how to use the resource. Thus, the iBook should be a self-directed resource.

5.4.10 NAVIGATION

"Navigation" corresponds to the degree of control that the user has when exploring the resource (Windle et al., 2007). Linear navigation occurs when the user has no possibility of altering the order of how to revise the e-learning tool. If the user has the freedom to direct the navigation, then the resource has an open navigation. iBooks use a mixed pattern, as they offer a linear navigation as a traditional book, but also due to the scrolling and search tool, the user can jump from section to section in an open manner (Payne et al., 2012). The degree of control that a resource requires is considered a key principle for effective e-learning. In principle, more experienced learners should have more freedom on how to use the learning tool (Clark and Mayer, 2011). This principle proposed by Clark and Mayer (2011) is aligned with Knowles andragogy theory which suggests that adults learn better when they self-direct their learning (Knowles et al., 2015). When using the Dundee iBooks, students can to use the tool at their own pace, having the possibility of deciding which chapter or page to explore first.

5.4.11 ASSESSMENT

Windle et al. (2007) established that the learning object should include a high level of assessment. One disadvantage of iBooks Author is that summative assessment is not possible as there is no scoring tool to collate answers (Payne et al., 2012). However, it allows questions to be added which can serve as practice to the learner. Therefore, the resource had formative assessment activities to reinforce the learning experience of the user. Evidence suggests that self-assessment is a good way to enhance the acquisition of abilities and to retain concepts and knowledge. Cook et al. (2010) in their meta-analysis collected evidence confirming that the use of self-assessment activities resulted in better knowledge acquisition. Therefore, iBooks should have sound and aligned formative assessment.

5.4.12 ALIGNMENT

This attribute is explained by Windle et al. (2007) as the existence of adequate alignment between evaluation and the learning goals. Constructive alignment is the main principle to consider as it establishes the correct association between the elements of an educational resource. Appropriate constructive alignment, directly relates to the intended learning outcomes, content and assessment methods contained in any learning tool (Biggs, 1996). Biggs (2002) explains that the “alignment” denotes what the facilitator does to achieve a set of defined learning outcomes. Meanwhile, the “constructive” component represents what the student has to do when using the resource to constructs learning. Following this recommendation, the e-learning tool needed clear learning objectives and activities, ensuing an appropriate alignment. Curry and Smith (2005) also suggested that the developer “clearly match the materials to the learning outcomes”.

5.5 FINAL PRINCIPLES AND GENERAL STRATEGIES USED TO DRIVE THE IBOOK INSTRUCTIONAL DESIGN

Table 5.7 summarises each of the principles derived from the twelve attributes described. The chart also includes the strategies used to comply with each principle. Further details on the development of the iBooks are explained in Chapters 7 and 9.

Table 5.7: Principles and strategies for the Dundee iBooks instructional design.

Attribute	Principle	Strategy
Interactivity	The iBook should be as interactive as possible.	This was achieved by the use of interactive elements, multimedia, interactive assessment and 3D interactive models throughout the iBook.
Objectives	The iBook should have clear learning objectives in accordance with the content.	This was done by setting the learning objectives and clearly stating them at the beginning of the iBook so students can recognise them.
Integration	The iBook should contain multi-media, making sure that they are properly integrated with the content.	The multimedia elements had a coherent structure and was easy to follow
Context	The iBook structure should depend on the context of the topic.	The topic was divided into sections, chapters and subchapters.
Media Richness	Media resources should be of high quality without affecting pedagogical attributes and use a semi-personalised informal language.	All media included in the iBook were created by IT experts and a professional photographer supervised by a professional dentist knowledgeable in the topic. The visual material was then revised by the researcher to ensure that the content was relevant and the information adequate.
Pre-requisite	The iBook should be easy to follow.	The strategy was to use simple language within the technical limits allowed by the topic. Overall the iBook had to be easy to follow.
Support	Simplicity and intuitive design will aid students' engagement with the resource.	This was achieved by paying attention to how the information was given. Adding tags, labels and short instructions so that the user could explore the iBook freely.
Feedback	The iBook should contain as much feedback as possible.	This was achieved by adding feedback to the interactive assessment activities provided in the iBook.
Self-direction	The iBook should be a self-directed resource.	The index allowed the user to scroll, search and direct to the desired section, chapter or page.
Navigation	The iBook should have some degree of navigational freedom.	This principle was achieved by the main structure of the iBook which had chapters, sections and pages; proving the possibility to move freely among the content.
Assessment	The iBook should have sound and aligned formative assessment, ensuring an appropriate reflective learning.	This was achieved by adding formative assessment activities after each section of the iBook. Here the students had the chance to monitor their learning progress and enhance the retention of knowledge.
Alignment	The iBook's learning goals, content and assessment activities should be properly aligned.	This was achieved by setting appropriate learning goals derived from the content and the assessment activities.

5.6 INSTRUCTIONAL DESIGN METHOD

Good practice for authoring an e-learning session demands a sound instructional design method. The literature describes various models suitable for this purpose. Examples include the Gagne's nine events for instruction, Dick and Carey Model, and the ADDIE model for instruction. The ADDIE models is one of the most popular models, due to its simplicity. Its name emerges from Analyse, Design, Develop, Instructional materials and Evaluate. Regardless it popularity, it lacks from a validation stream and formal author. On the other hand, The Dick and Carey model, developed in 1978, is more extended and contains 10 elements such which are interconnected. Examples of the steps of the instructional design are: identify the instructional goal, conduct instructional analysis, develop instructional strategies, revise instruction and design and conduct summative evaluation (Bristol and Zerwekh, 2011).

Using a student-centred approach is the most recommended path to enhance learning (Koohang et al., 2009). For the development of the iBooks, the researcher opted to apply the nine steps of the Gagne model, blended with the twelve principles described in the previous section.

Gagne's steps are a systematic model well known and recognised in the field of medical education (Khadjooi et al., 2011). They have also been used for the creation of e-learning materials (Gordon et al., 2013; Bristol and Zerwekh, 2011). This choice was made to ensure high quality (Gordon et al., 2013), simplify the construction process and ensure that all steps had the proper instructional design.

Another reason for adding this method was due to its familiarity among academics, a fact that might simplify the production of future iBooks in the dental field.

The next section presents and explains the nine steps for instructional design proposed by Gagne in the context of the iBooks created for this study.

5.6.1 GAGNE'S 9 STEPS FOR INSTRUCTIONAL DESIGN

STEP 1: GAINING ATTENTION

Walker (2008) suggests that gaining attention is critical for a learning session to be successful. In face-to-face learning, a firm tone and an open attitude which invites dialogue (Light et al., 2009) have had a positive impact on students. However, to achieve that level of impact in e-learning can be more challenging as the attention has to be gained by images, written words, or another sort of medium. In the field of e-learning Keller and Suzuki (2004) proposed a model named ARCS (Attention, Relevance, Confidence, and Satisfaction). The first step highlights the importance of gaining the learners attention to stimulating their sense of inquiry. Showing the users the importance of using the iBook could attract their attention. When learners are aware of the importance of learning, deep learning is promoted (Knowles et al., 2015).

STEP 2: INFORMING LEARNER OF OBJECTIVES

Knowing in advance what is to be learned is key for learning (Knowles et al., 2015). Harden (2002) explains that students can achieve a greater sense of ownership when they know about the learning objectives. Also, a sense of transparency is reached when students know what to expect and what is expected from them

(Harden, 2002). Additionally, successful distance learning material has to inform students about the learning goals of the module (Kavadella et al., 2013).

STEP 3: STIMULATE RECALL OF PRIOR LEARNING

Stimulating recall can help the learner build new learning and stimulate the short and long working memory (Bristol and Zerwekh, 2011). Past experiences have been suggested by multiple authors to be important to achieve meaningful learning (Collins, 2004; Lieb and Goodlad, 2005; Merriam, 2001; Kaufman, 2003). Therefore, helping students recall prior knowledge and experiences, has the potential to promote the acquisition of new learning, giving them the chance of constructing new learning on top of their previous knowledge.

STEP 4: PRESENTING THE CONTENT OR STIMULUS MATERIAL

Bristol and Zerwekh (2011) recommend using a wide variety of methods to attract students' attention, motivate and coax them into participation. Best practice suggests that importance of the topic enhances motivation (Hodges, 2004) by means of meaningful learning materials (Khadjooi et al., 2011). Also, consistency between the content activities and the learning goals has proved to be essential when presenting the material (Keller and Suzuki, 2004). Motivation is a concept that repeatedly relates to adult learning principles as it promotes deep learning (Lieb and Goodlad, 2005; Merriam, 2001; Kaufman, 2003; Knowles et al., 2015). Moreover, Mann (1999) suggests that it is important to develop adequate strategies to present the learning material to stimulate the learner's inner motivation.

STEP 5: PROVIDING LEARNING GUIDANCE

Good practice includes the use of resources and strategies that assist the learner throughout the learning process (Bristol and Zerwekh, 2011). Explicit instructions can guide novice learners through the learning material. Likewise, it has been proposed that advanced learners benefit from clear instruction and guidance (Kirschner et al., 2006). Two techniques suggested by Knowles et al. (2015) attempt to orientate the learner in the process; using a problem-based approach and placing the content in context.

STEP 6: ELICITING PERFORMANCE

This step refers to those activities that stimulate the student to “do” things. Giving students the opportunity to practise, reflect, experiment, explore, solve, provide feedback and interact has a positive effect on learning. Using these strategies can promote sustainable learning as the learner becomes active in the construction of learning (Murphy, 1997; Kaufman, 2003).

STEP 7: PROVIDING FEEDBACK

Formative feedback has a great impact on learning (Biggs and Tang, 2011) as it allows the learner to identify where their skills, and/or knowledge need to be amended (Perera et al., 2008). This recognition makes the learning process deeper and more meaningful. Additionally, feedback enhances motivation (Hodges, 2004), and providing feedback is one of the requirements for good practice for well-designed medical education packages (Childs et al., 2005). Therefore, space for feedback must be provided within the learning resource.

STEP 8: ASSESSING PERFORMANCE

This stage of the Gagne plan looks for students to demonstrate the acquisition of knowledge or skills. For the construction of this learning tool, formative assessment was considered. Formative assessment can be a formal or an informal way to provide a learning opportunity to students (Yorke, 2003). Formative assessment is designed mainly to provide feedback which helps to promote motivation, reflection and self-direction (Wood, 2010). The use of formative assessment, attempts to offer space to participants to integrate and demonstrate the learned concepts allowing them to confirm their understanding (Khadjooi et al., 2011). To accomplish effective formative feedback it has to be linked with a formative assessment method (Wood, 2010) which generates an instance of reflection that facilitates learning in students. The researcher included formative feedback in the iBooks in the quiz sections

STEP 9: ENHANCING RETENTION AND TRANSFER

This step is about the long term retention of concepts and transfer into practice of the learned skills or knowledge. Khadjooi et al. (2011) suggested that repetition and rehearsal are good ways to enhance retention. The possibility of reviewing the tool, as often as wished, offers the possibility of better anchoring of the learned concepts. Additionally, the design aimed to motivate the user; thus promote and enhance learning.

5.7 CONCLUSION

This chapter demonstrates that creating an RLO from scratch can be challenging. Advantages of using learning objects described by Harden and Hart (2002, p.264) include that "*e-learning allows such learning objects to be easily accessible and found, and to be easily updated.*" Ensuring access and clarity of e-learning has the potential to promote effective learning.

The chapter looked at the authoring process of the e-learning resource, presenting key concepts and principles for the instructional design of the Dundee iBooks. Evidence presented in this chapter linked key principles for e-learning with relevant educational instructional design methods for the proper authoring of an educational tool. Ensuring the technical and educational aspects of the resource provides a sound starting point to the design process. Other aspects to consider for the successful creation of e-learning modules for dental education are forming an adequate team and having peer-review feedback (Kavadella et al., 2013). These and other specifications included in the authoring process are discussed in Chapters seven and nine.

6 DETERMINING THE TOPICS FOR THE DUNDEE DENTAL SCHOOL IBOOKS

6.1 INTRODUCTION

This chapter describes how the researcher selected the two topics for the iBooks. The results of the first study (Chapter three) revealed several areas of dentistry that would benefit from the creation of a 3D e-learning resource, based on the views and needs of different stakeholders from four dental schools.

6.2 THE TOPIC FOR THE FIRST iBOOK

One reason for selecting the topic for the first iBook centred on the fact that one of the current projects at the Dundee Dental School centres on the development of a set of 3D models representing the anatomy of the complete permanent dentition. Considering the availability of these 3D resources the researcher developed an iBook about tooth morphology. The findings from chapter three showed that "tooth anatomy" was among the first third of the prioritised items.

In general terms, the aim of this first iBook was to guide and inform the authoring process of a second iBook also produced in the Dundee Dental School.

6.2.1 TOOTH MORPHOLOGY

Tooth morphology is an essential subject in dentistry. Dentists need to become experts in tooth anatomy as it has profound implications in mastication, aesthetics, speech and occlusal functioning. The UK General dental council (GDC) stipulates that a qualified dentist needs to: "*Describe relevant dental, craniofacial and oral anatomy and explain their application to patient management*" (GDC, 2015 p. 52).

Therefore, dental students need quality teaching methods to ensure good long-term learning about dental anatomy.

At the Dundee Dental School tooth morphology is currently taught using lectures and seminar sessions. Usually, the practical interventions involve the use of plastic replicas and real tooth specimens, which students cannot take away from the dental school. However, they can borrow these materials and use them inside the university. This restricted access to the learning materials limits students as to when and where they can study. The suggested tooth morphology iBook addresses this issue by providing a 3D learning resource that can be used anywhere at any time.

Many authors have addressed the importance of tooth morphology and created several e-learning tools to acquire a better understanding of this topic (Cantin et al., 2015; Mitov et al., 2010; Nagasawa et al., 2010; de Boer et al., 2013). However, none of these resources is similar to the iBook designed in the Dundee Dental School. For complete details about the construction and evaluation of the resource please refer to Chapters seven and eight respectively.

6.3 THE TOPIC FOR THE SECOND IBOOK

The selection process for the second iBook demanded a deeper insight as this iBook was intended to assess the 3D impact and it was an original creation. The topic needed to be relevant for the dental community and comply with the framework of this study in terms of time, cost and resources availability. Therefore, the researcher created eight statements, assessed with a YES or NO answer based on five criteria. Each criterion emerged from the literature review, the results of Chapter three, key educational concepts and the limitations of this study. The five criteria were: “priority”, “resource required”, “suitable content”, “educational impact” and “resource availability and suitability for purpose”. Table 6.1 explains each criterion. The idea was to determine which topic from the initial study scored the most positive answers. The top ten items obtained from the rankings shown in Chapter three were used.

Table 6.1: Criteria considered for the topic selection

Criterion	Explanation
Priority	This criterion emerged from the results of the first experimental session undertaken in this study, which aimed to prioritise dentistry topics that had a need of 3D learning resources.
Resource availability	This criterion emerged from the literature review. It referred to the previous existence of 3D resources for dental education. It also paid attention to the quality and completeness of the available resources.
Suitable content	This criterion looked at the suitability of the content of the new resource considering two main aspects. The first was if there were academics knowledgeable in the subject involved with the study and secondly if the topic was appropriate for a resource that contained 3D elements such as models, simulations and animations.
Educational impact	This criterion emerged from the current areas of dentistry where there is still controversy in terms of standardisation for teaching and learning due to their complexity. Educational impact was understood as the possibility to aid with daily teaching/learning of complex dental topic.
Suitability for purpose	This criterion emerged from the feasibility study undertaken and the research plan to assess the resource. Overall, the criterion served to determine if the topic would be suitable to conduct this study considering the limitations.

a) Criterion 1: Priority

Rankings are a simple and widely used method to prioritise data (Lees and Lievaart, 2013). They also allow a large amount of data to be prioritised more quickly (Saaty, 2008). Therefore, a ranking was prepared using all participants who took part in study one. Only the top ten items were considered to determine the topic of the new iBook and can be seen in Table 6.2. Thus, the following statement was used:

The topic is among the "top ten" items observed in the ranking of Chapter three.

b) Criterion 2: Resource availability

One key aspect of any feasibility plan is to justify the need for the construction of the new product. In this case, the need for the development of a 3D learning resource is underpinned by the lack of specific resources addressing dental education topics. Based on the evidence gathered in the literature review, there are few subjects in dentistry that use 3D digital models. Thus, the following statement was created to assess the existence of such resources and clarify if the construction of a new resource is required: **This 3D resource will be the first one addressing adequately the topic**

c) Criterion 3: Suitable content

Validity implies that a certain measurement system measures what it intends (Van Der Vleuten and Schuwirth, 2005; Long and Johnson, 2000). As validity is not a numerical concept its definition is not absolute and therefore several types of "validity" can be found. The most relevant one for this stage is "content validity". Van der Vleuten (2000) stated that an instrument has good content validity when its design has an adequate range of topics representing what it is intended to be measured. In other words, good content validity is achieved when there is certainty that the topic is properly addressed by the instrument. Application of content validity in assessment ensures that an evaluation tool measures what it is supposed to measure (Bordage et al., 1995). Expert judgement is a common way to assess content validity (Berk, 1990; Steinberg et al., 2007). The researcher created the following statement to ensure content validity: **Experts in this topic are part of the team in the study.**

Also, it was mandatory that the constructed resource contained 3D elements that could be represented using models, simulations or/and animation by means of 3D virtual technology. The following statement addressed this issue: **The topic can be explained using 3D models, simulations or/and animations.**

d) Criterion 4: Educational Impact

The researcher wanted to develop a resource able to contribute to dental education. Thus, the e-learning resource needed to have a positive impact on learning and facilitate teaching. Choosing a complex topic was mandatory and so, the following statement was created: **The topic is complex to teach and/or learn using traditional methods.**

The item needed to be suitable for undergraduate students as they were the targeted group to assess the resource. The following statement represented this issue: **The topic is appropriate for undergraduate students.**

e) Criterion 5: Suitability for purpose

Suitable facilities and resources for the construction of the 3D e-learning tool were mandatory. Therefore, the time required, cost and resources were considered. A feasibility study was conducted and determined that iBooks Author was the most suitable authoring package to use. Further information can be found in Chapter three. This information informed the following statements: **Technological facilities are available to develop the 3D learning resource.** And: **The development of the resource in this topic fits the time and cost frame of this PhD.**

6.3.1 RESULTS OF THE ANALYSIS

Table 6.2 presents all the statements and the top ten topics analysed. Each statement was answered with YES or NO to indicate which of the topics was most appropriate to use for the iBook. The research team scored the top ten items using the criteria listed above.

The subsequent analysis revealed that Anatomy of the temporomandibular joint was the most suitable topic as it collected more YES answers.

Table 6.2: Analysis of the top ten items using the proposed statement

Criterion / Top 10 Item	The topic is among the "top ten" items observed in the ranking of Chapter three.	This 3D resource will be the first one addressing adequately the topic	Technological facilities are available to develop the 3D learning resource.	The development of the resource in this topic fits the time and cost frame of this PhD.	The topic is appropriate for undergraduate students.	The topic can be explained using 3D models, simulations or/and animations.	Experts in this topic are part of the team in the study.	The topic is complex to teach and/or learn using traditional methods.
Anatomy of the TMJ space	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Anatomy of trigeminal nerve	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Concepts in occlusion	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Head and neck anatomy	Yes	No	Yes	No	Yes	Yes	No	Yes
Local anaesthesia techniques	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Occlusion functioning and types	Yes	Yes	Yes	No	Yes	No	Yes	Yes
Root canal treatment model	Yes	Yes	Yes	No	Yes	Yes	No	No
Surgical procedures for implants	Yes	No	Yes	No	No	Yes	No	No
TMJ dysfunction	Yes	Yes	Yes	No	Yes	Yes	No	Yes
Tooth and cavity preparation	Yes	No	Yes	No	Yes	Yes	Yes	No

6.4 THE IMPORTANCE OF THE TMJ

The temporomandibular joint (TMJ) is a dual joint responsible for all the dynamic and static relationships between the jaw and the maxilla. This complex joint is intimately related to teeth; their functioning and occlusion of the masticatory system. Therefore, its correct understanding is crucial for successful dentistry.

Despite its relevance, some dental curricula such as the one used in Dundee Dental School do not have an independent module for dental occlusion and function of the temporomandibular joint. However, to enhance the connection of theory and practice the TMJ it is addressed in various modules of the course. The General Dental Council (GDC) stated dental students should be able to *“Describe relevant dental, craniofacial and oral anatomy and explain their application to patient management”* and, “*Recognise and manage temporomandibular joint disorders*” (GDC, 2015 p.52 and p.90). These two statements are broad leaving space for uncertainty, as a consequence the current way of addressing TMJ pathology is not standardised. The literature reveals discrepancies and differences when addressing TMJ disorders. Okeson (2013) has identified the need to have total understanding of the TMJ before studying the TMJ disorders. Additionally, many authors have identified the complexity of the teaching and learning of the temporomandibular disorders and occlusion (Türp et al., 2008; Ash, 2007; Stockstill et al., 2011). Moreover, disagreement exists in basic terminology related to the function of this joint (Jasinevicius et al., 2000; Stockstill et al., 2011).

Producing an iBook addressing the functional anatomy of the TMJ has the potential to generate real educational impact.

The clinical importance of the TMJ, the results of Chapter three two of this project and the feasibility study are all reasons to justify the development of TMJ for the iBook.

6.5 CONCLUSIONS

The current chapter explains how the topics for the two iBooks were chosen. The first choice followed a convenience technique, considering that part of the 3D material was already available. The second used prior information collected in this research as the topic demanded the creation of 3D models from scratch. The final decision was to select Tooth morphology and Anatomy of the temporomandibular joint as the two topics for the Dundee Dental School iBooks.

7 THE DUNDEE DENTAL SCHOOL TOOTH MORPHOLOGY IBOOK

7.1 INTRODUCTION

This chapter describes in detail the authoring process of the Tooth morphology iBook. The researcher used Gagne's nine steps (Gagne and Briggs, 1974) for instructional design and considered the principles for e-learning presented in Chapter five.

This chapter has two main parts. The first part presents the nine steps for instructional design and their application during the authoring process. The second part, explains how the elements were created, assembled and revised.

7.2 STEPS FOR INSTRUCTIONAL DESIGN: THE TOOTH MORPHOLOGY IBOOK

STEP 1: GAINING ATTENTION

It was essential to engage students when they start using the iBook. Therefore, the introduction was short, informative and attractive. To maintain the attention of the user, the language was simple and the information succinct.

The opening page of the iBook (Figure 7.1), contained the following question: "Why study tooth morphology?". This question wanted to make students think about why this subject was important for dentistry. Four clinical photographs provided the most important reasons why tooth morphology should be studied. The photographs were used in the iBook as interactive images able to display a pop-up when the user tapped them; an example can be seen in Figure 7.2. Using interactive images is aligned with the interactivity principle for e-learning proposed by Moreno and Mayer (2007).

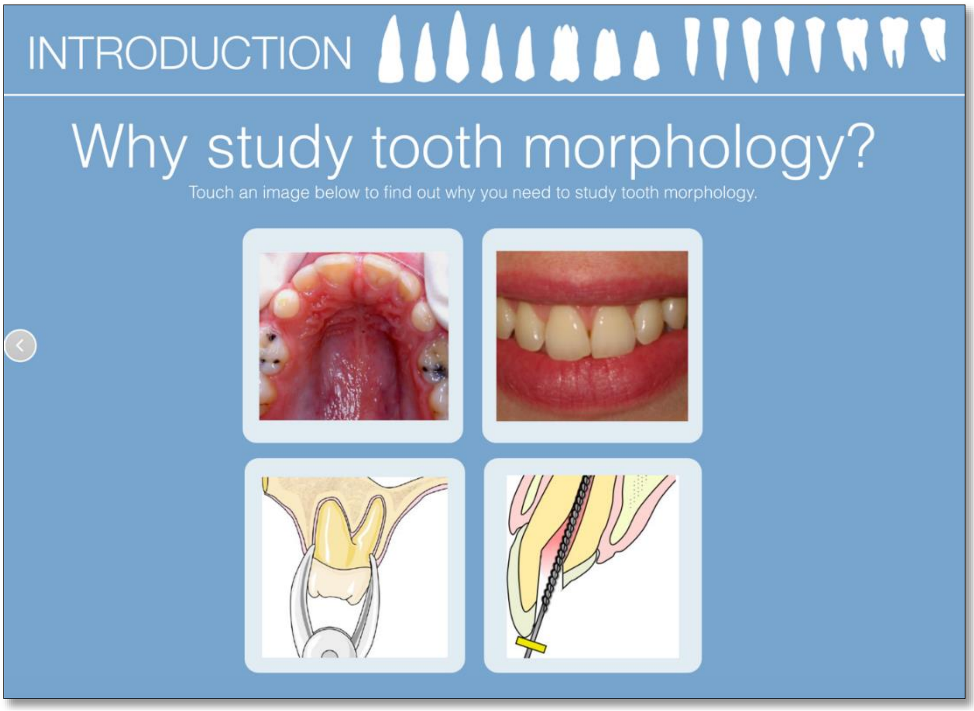


Figure 7.1: Introduction page of the Tooth Morphology iBook

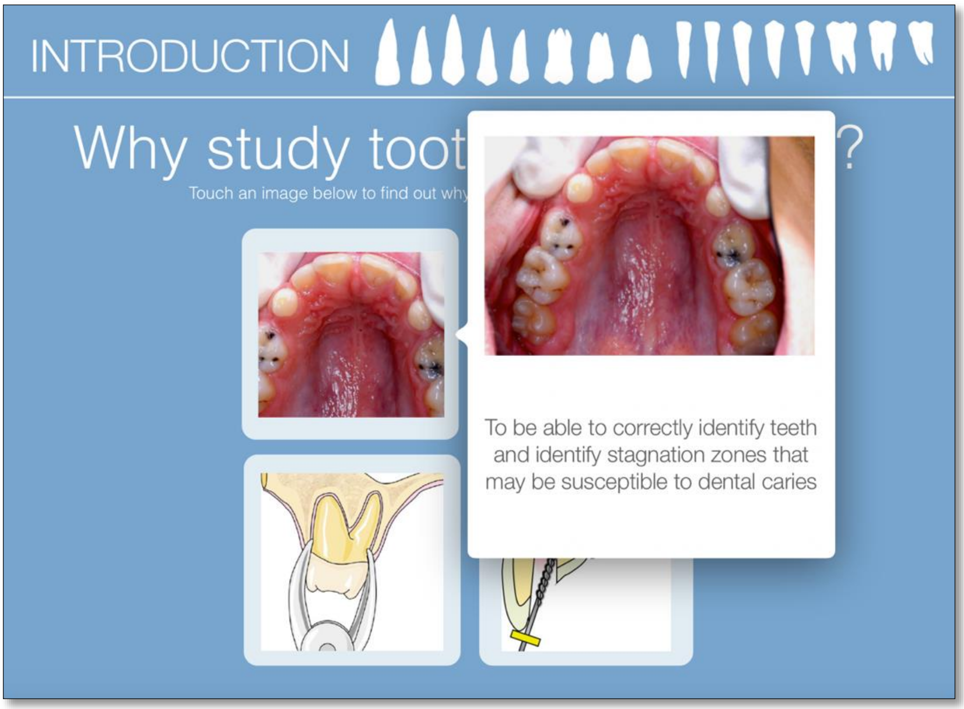


Figure 7.2: Introduction page displaying an interactive pop-up image after activation

STEP 2: INFORMING LEARNER OF OBJECTIVES

The learning objective and topic of the iBook were presented on its first page. This page included an instructional video about how to use the iBook (Figure 7.3). This video was created using Camtasia Studio software (TechSmith Corporation. Okemos, MI, USA). Camtasia is a "screen video capture" software. When activated it captures the action on the computer screen permitting the creation of explanatory videos (TechSmith-Corporation, 1987). The use of an instructional video is aligned with the support principles proposed by Windle et al. (2007) discussed in Chapter five.

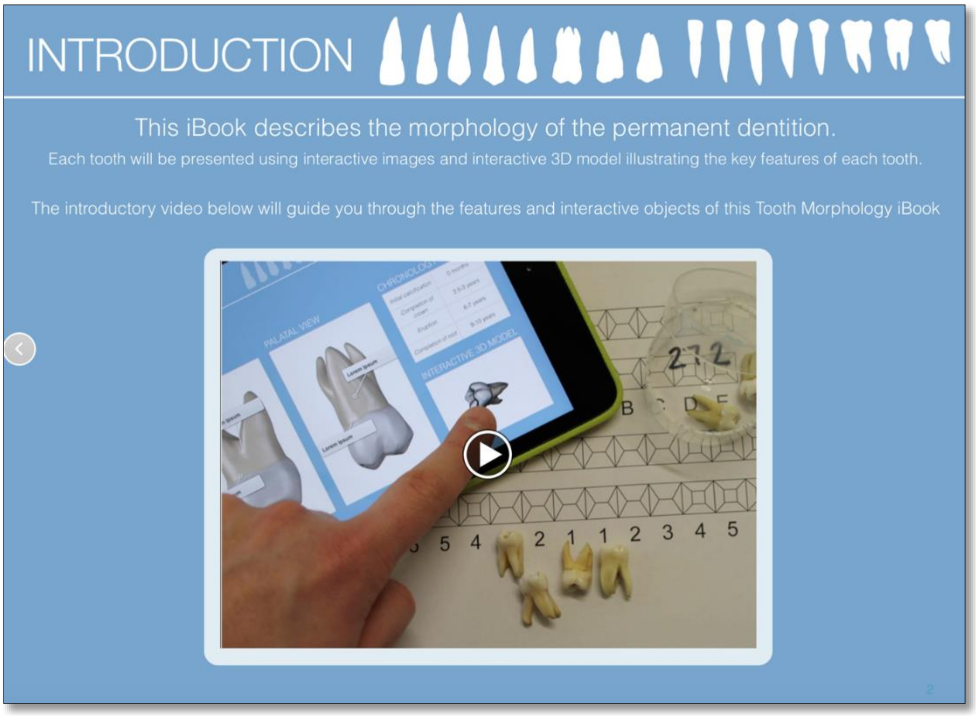


Figure 7.3: Introductory video that provided instructions of how to use the iBook.

STEP 3: STIMULATE RECALL OF PRIOR LEARNING

The introduction section provided an overview of the relevant terminology. Pages three and four of the iBook contained the complete dental arches nomenclature to encourage students recall their previous knowledge; e.g. FDI nomenclature. Brief instruction of how to use the interactive models was also included. When the user touched the model, it displayed a tag with the nomenclature of the tooth. These interactive features are shown in Figure 7.4 and 7.5.

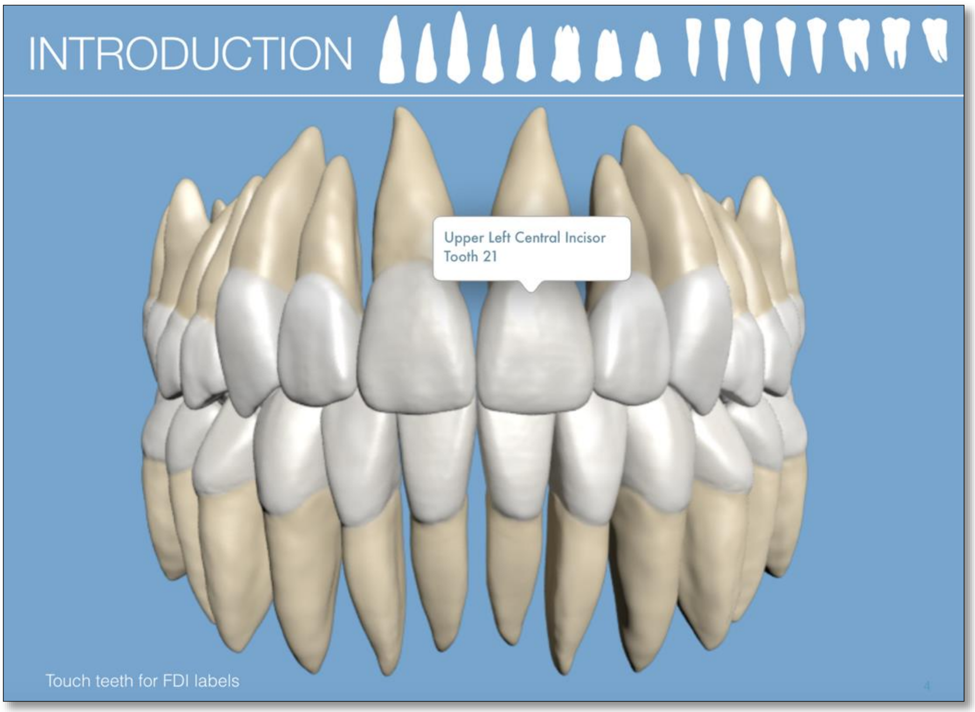


Figure 7.4: Example 1: tooth nomenclature displayed using an interactive pop-up

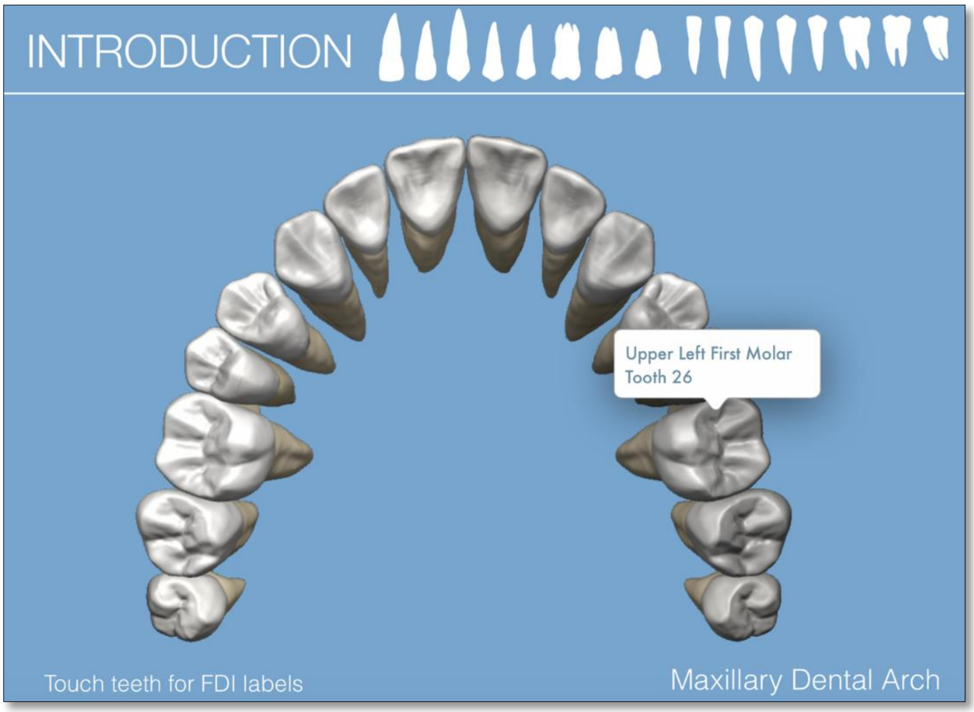


Figure 7.5: Example 2: tooth nomenclature displayed using an interactive pop-up

STEP 4: PRESENTING THE CONTENT OR STIMULUS MATERIAL

The Tooth morphology iBook was divided into chapters and each chapter was subdivided into a series of pages. Each group of teeth had their own chapter, starting with the anterior teeth and progressing to the posterior molars. All the sections contained an opening page providing general information about each group of teeth (Figure 7.6).

Figure 7.6: Chapter opening page.

The content elements were placed favouring symmetry and an organised distribution. The anatomical details of each teeth were given using features such as: interactive galleries, interactive images, 3D models, tables and text boxes. Information about eruption and calcification was also provided, plus a brief written description of the main features of each group of teeth (Figure 7.7 and 7.8).

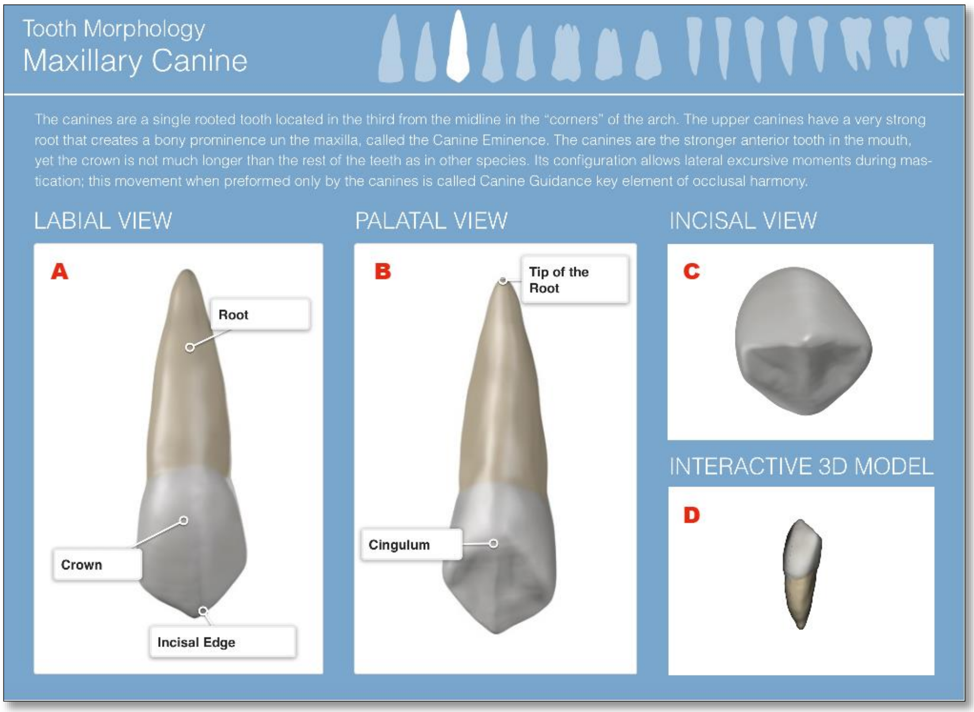


Figure 7.7: Content elements arranged in the iBook, page 1.
A and B: Interactive images. C: Static image. D: Interactive 3D model

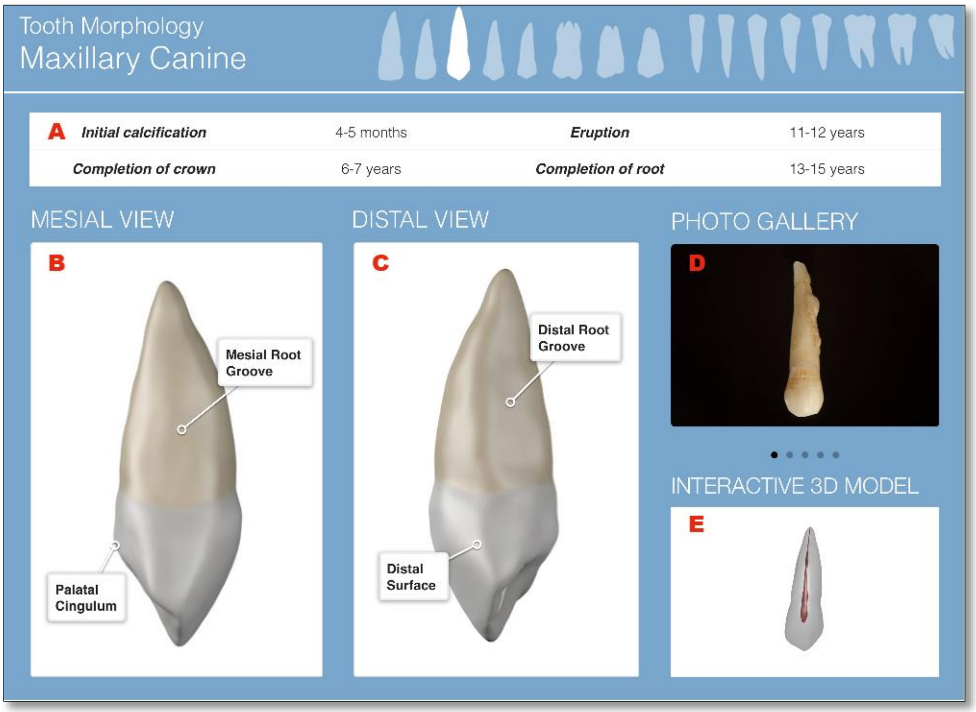


Figure 7.8: Content elements arranged in the iBook, page 2
A: Table with calcification dates. B and C: Interactive images. D: Interactive gallery. E: Interactive 3D model

All the teeth were represented using interactive images. These interactive images were static views with tags. When the user tapped them, the tags displayed further information (Figure 7.9).

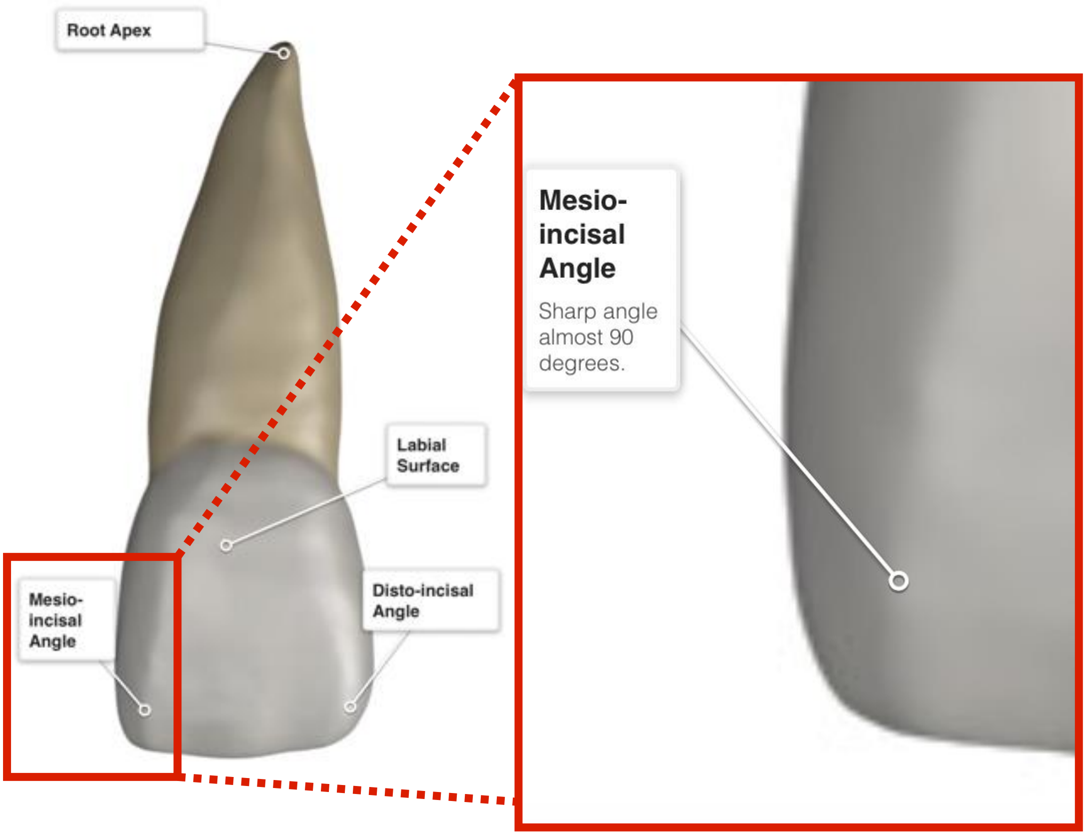


Figure 7.9: Interactive image, before and after activation of the interactive tag.

The most relevant features were the use of 3D interactive models which represented the external and internal anatomy of each tooth. When the user tapped the interactive model it expanded using the complete screen of the iPad (Figure 7.10). The user could freely interact with the model. They could rotate, zoom and move the model as required.

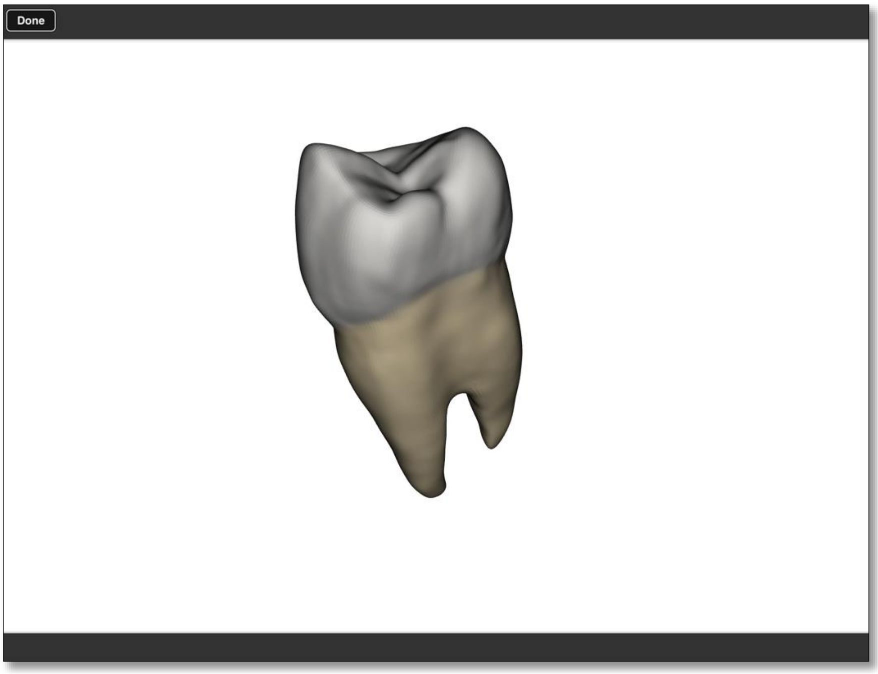


Figure 7.10: Example of the 3D interactive models displayed in the full screen of the iPad

A gallery contained a sequence of detailed photographs of natural teeth (Figure 7.11). The aim of this gallery was to provide students with a real version of each of the teeth and molars. When the user tapped the gallery, the photograph expanded using the complete screen of the iPad. The user had to scroll to the side each image to move to the next one.

Figure 7.11: Example of a sequence of photographs contained in the interactive galleries.

STEP 5: PROVIDING LEARNING GUIDANCE

All the interactive features and galleries helped the student to use the resource intuitively, without missing any information. Additionally, explicit instructions of how to use the iBook were given in the introductory video. In the quiz section, each question had instructions to guide the student. Question format were given by the authoring package. Among the alternatives the researcher could select from multiple choice questions, “drag and drop” and “drag thumbnail to target” type of questions. An example of a “drag and drop” question and instructions is shown in Figure 7.12.

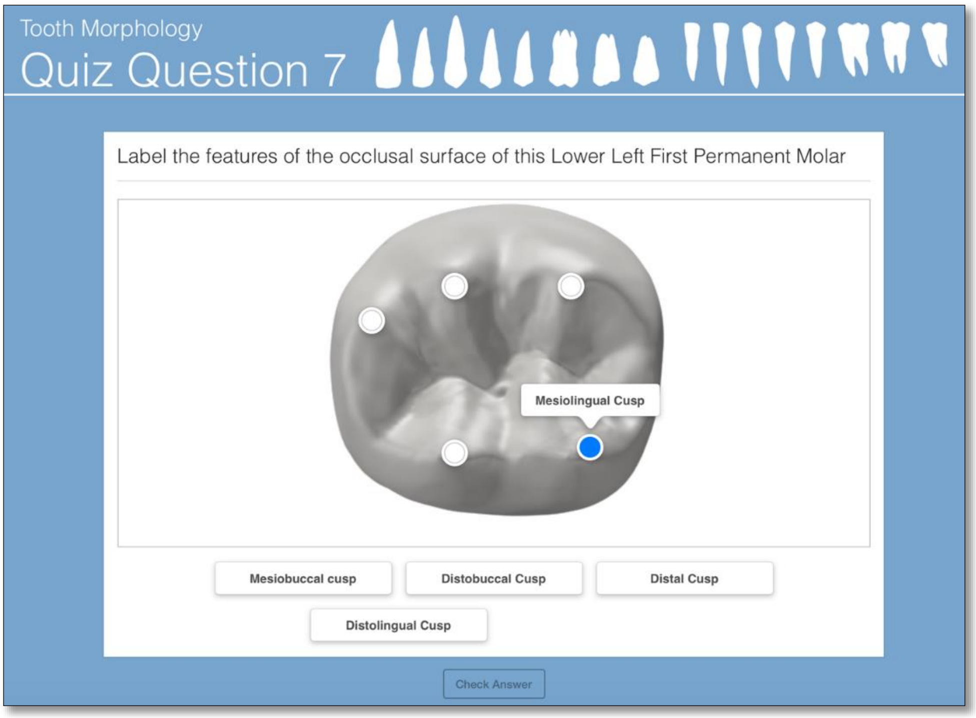


Figure 7.12: Example of instruction given in quiz section

STEP 6: ELICITING PERFORMANCE

The layout of each chapter helped the user to reinforce their understanding of concepts and explore each tooth. After finishing the quiz, students could check their answers to assess their performance and repeat the test if desired.

STEP 7: PROVIDING FEEDBACK

A quiz section containing drag and drop and multiple choice questions was created at the end of the iBook to provide feedback to students. After answering a question the student received immediate feedback. Formative feedback was used in questions that required detailed explanation. This feedback was given using pop-up boxes containing the relevant information (Figure 7.13).

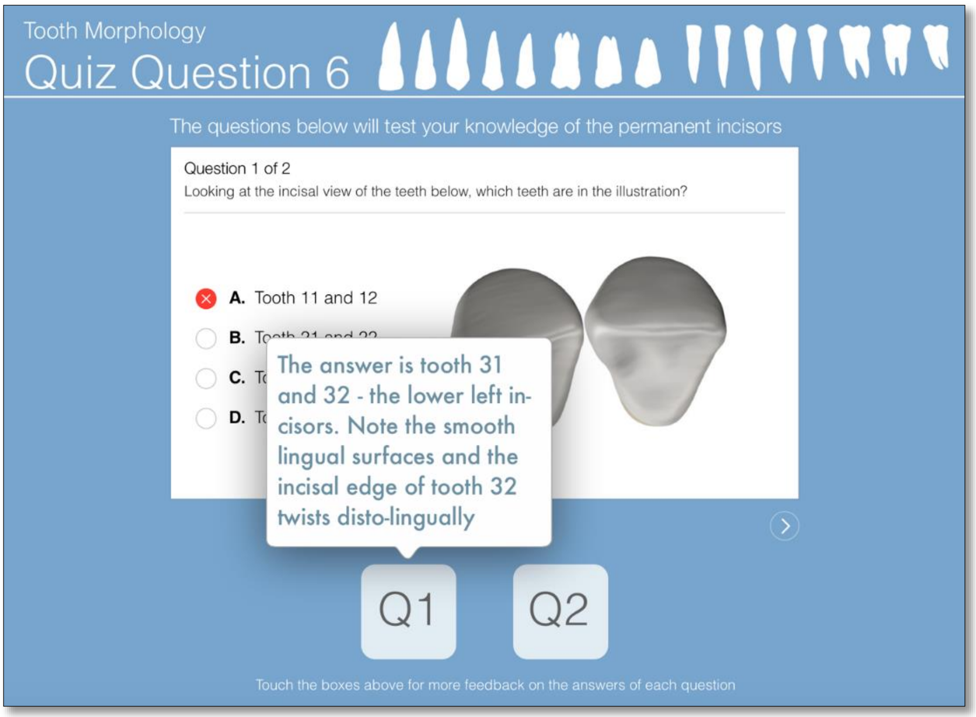


Figure 7.13: Example of feedback provided in quiz section

STEP 8: ASSESSING PERFORMANCE

As explained in Step 7, formative assessment exercises were included in the iBook. These exercises aimed to give students the chance to practice. Summative assessment was not added in this learning resource as iBooks Author did not have the adequate tools to support this type of evaluation.

STEP 9: ENHANCING RETENTION AND TRANSFER

To enhance retention the iBook allowed the user to make notes and comments while using the resource (Figure 7.14). Also, in certain pages of the iBook a comparison between similar teeth was provided to help students with the retention of the specific features (Figure 7.15). Once the user completed the quiz section, they could repeat the exercise. Additionally, the user could scroll back and forward to revise particular sections of the iBook.

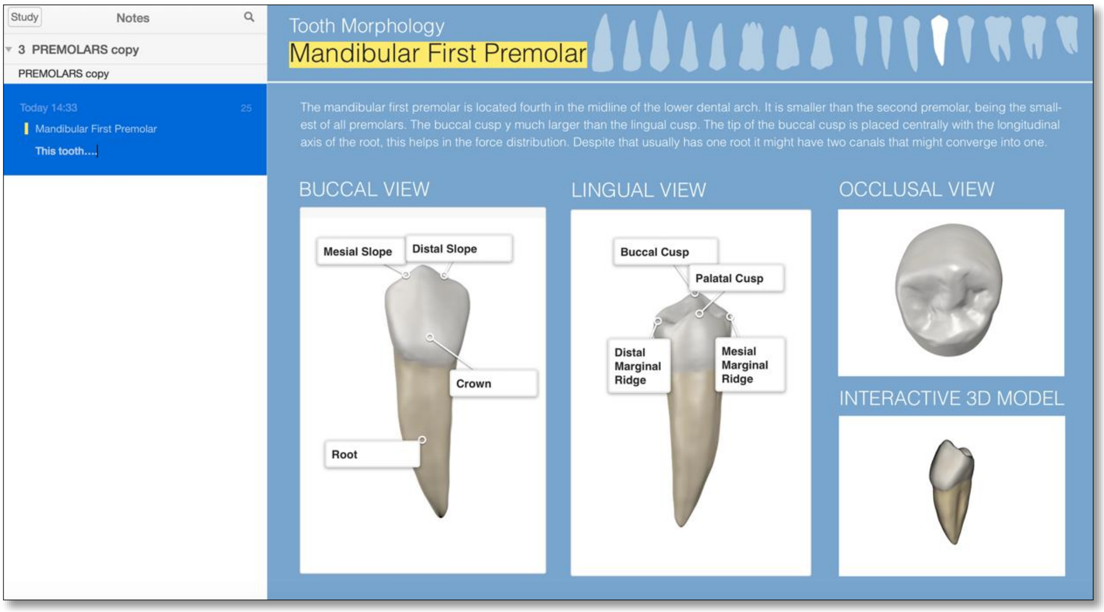


Figure 7.14: Comments addition process to the iBook during its revision

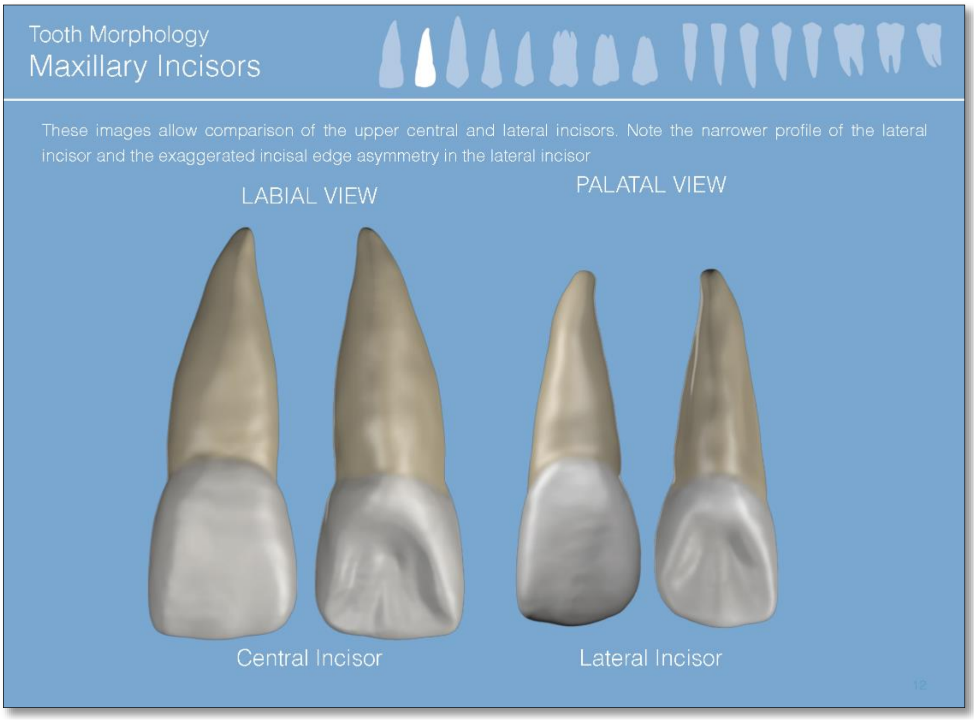


Figure 7.15: Comparison between two similar teeth

7.3 THE PRODUCTION

The production was divided into three stages: the creation of the components, the assembly and testing of each of the elements and the quality assurance process.

7.3.1 CREATION OF THE COMPONENTS

a) 3D MODELS

A medical artist developed the 3D models for all permanent teeth. The 3D models were created using Zbrush (Pixologic Inc.California, USA) and Maya (Autodesk, Inc. California, USA) software. However, to obtain the initial models a surface scan of anatomically perfect teeth was taken. The literature shows that scanning has been one of the most used techniques to extract anatomical features of teeth for the creation of digital models. (Cantin et al., 2015; Mitov et al., 2010; Nagasawa et al., 2010; de Boer et al., 2013). The method involves computing scanning of a solid structure (e.g. cast or plastic model) able to replicate its shape in a computer. The scanning method is a fast and easy way to obtain 3D models replicating accurately the dimensions and details of a structure. Figure 7.16 shows an example of a scan obtained from the anatomically perfect model.

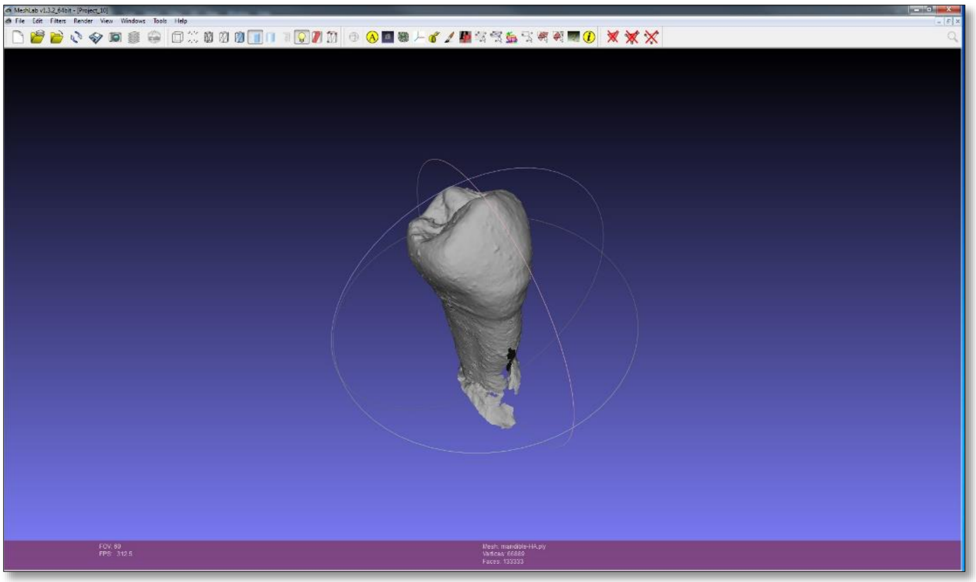


Figure 7.16: Scan of the anatomical model

The scanning process generates polygons. A polygon is a geometric figure with three or more sides, composed of faces, edges, vertices and a normal surface. The modelling process involves the creation, extrusion and attachment of polygons to create an object (Flaxman, 2008). After obtaining each scan, the medical artist uploaded the files to Maya, to reduce and arrange the number of polygons of the structure. The roots of the teeth and molars were hand-modelled replicating the anatomy of real specimens. Then the digital models were polished (digitally smooth) and painted.

In 3D modelling, painting is done by adding a texture map to the model. Texture maps provide the superficial characteristics and colour to the 3D structure. The texture maps are created by the modelling artist giving the model the most realistic outlook. Figure 7.17 shows a sequence for the development of the 3D model of a tooth.

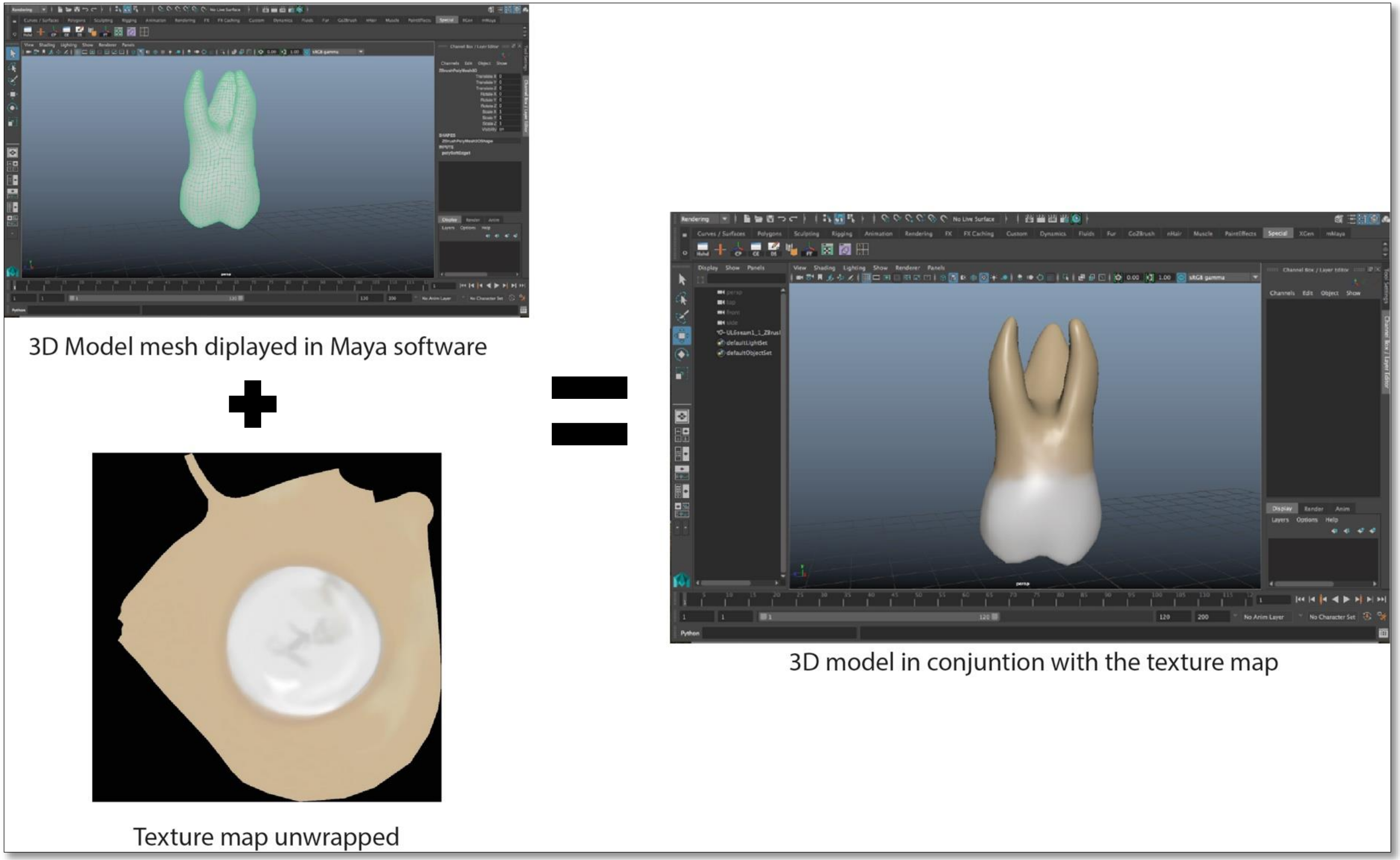


Figure 7.17: Sequence for texturing a 3D model

As each tooth had two 3D models a secondary texture map was developed to create the transparent models representing the anatomic structure of the root canals and pulp chamber. These models offered students the possibility to obtain a clearer idea of the internal anatomy of each tooth (Figure 7.18)

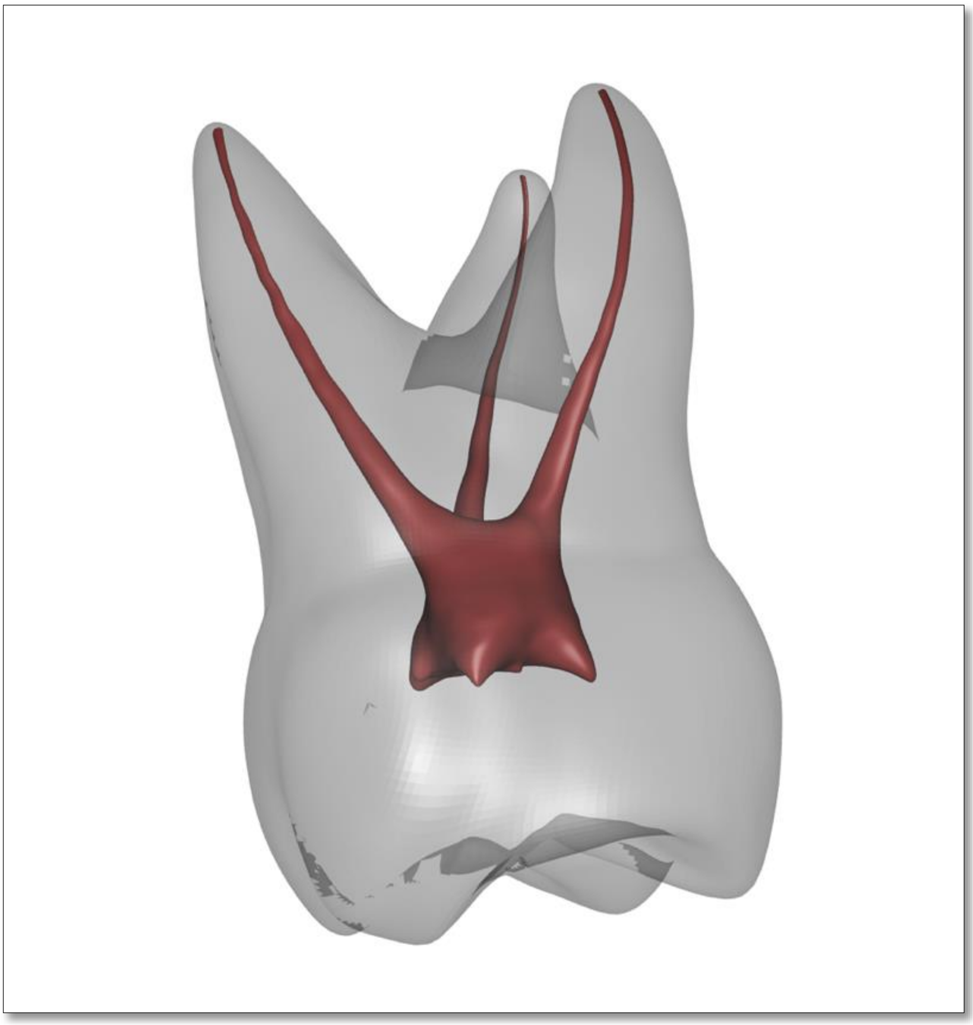


Figure 7.18: Transparent molar

Once the 3D models were finished, they were exported as Collada files. The term Collada comes from **Colla**borative **d**esign **a**ctivity and is identified by ".dea". This type of files uses a format that allows transporting 3D asset data among several applications maintaining its 3D properties and the moving characteristics of the model (Miyahara and Okada, 2009). This means that once the model is in a Collada .dea format, the file can be inserted into a program such as iBooks and the user can freely interact with the model. iBooks Author accepts these type of files, however, files larger than 20 megabytes are not accepted by the authoring package. This size restriction proved a problem with some models, as the scanning process provided a very detailed mesh with many polygons. The complexity of a 3D model is measured by the number of polygons and generally speaking the size of the file has a direct relationship with the number of polygons that the structure has. Reducing the size of the file without losing details of the 3D model was a challenge.

b) 2D IMAGES

The images used in the iBook were screen captures of the 3D models representing the vestibular (buccal), palatal/lingual, mesial and distal views. Occlusal views from premolar and molars were also captured to explain the anatomical features of the occlusal surface. Figure 7.19 shows examples of some of these views.

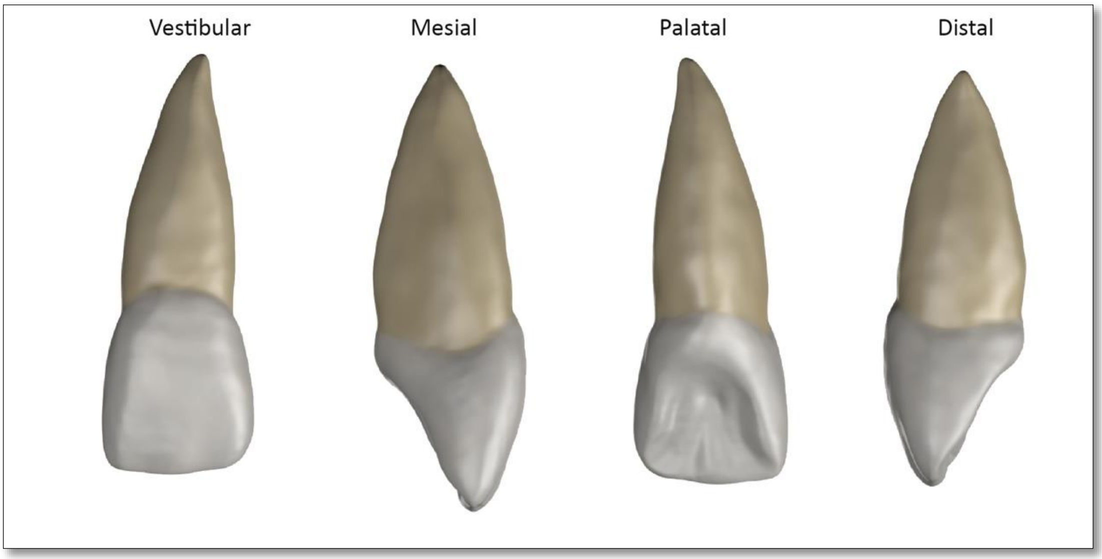


Figure 7.19: Captured images from the 3D models representing views of the teeth.

c) CLINICAL PHOTOGRAPHS

The clinical photographer from the Dundee Dental School took professional images of real teeth. To standardise each photograph a black background was selected, this enhanced the natural colours and features of each tooth. Figure 7.20 shows an example of the resulting images.

Figure 7.20: Example of the photographs used in the iBook

d) VIDEO

In the introduction section, a video was used to explain how to use the iBook. This video was created by the medical artist using Camtasia Studio software (TechSmith Corporation. Okemos, MI, USA).

e) TEXT

Recognised tooth morphology textbooks were consulted for the content development (van Beek, 1983; Lucas, 2004). This was limited to the most important aspects and characteristics of each teeth. The language used was simple and avoided repetition.

f) Questions for the quiz section

The researcher designed nine questions trying to address the most relevant information provided in the iBook without making the section too bulky.

7.3.2 ASSEMBLY AND TESTING OF THE COMPONENTS

a) Assembly and design

iBooks Author uses a very intuitive layout which simplified the design task. Even someone who is not familiar with the software can use it. iBooks Author working page has the main bar where the user can select a command, for example, edit, insert, format, arrange. Figure 7.21 exhibits an example of how a tool can be selected.

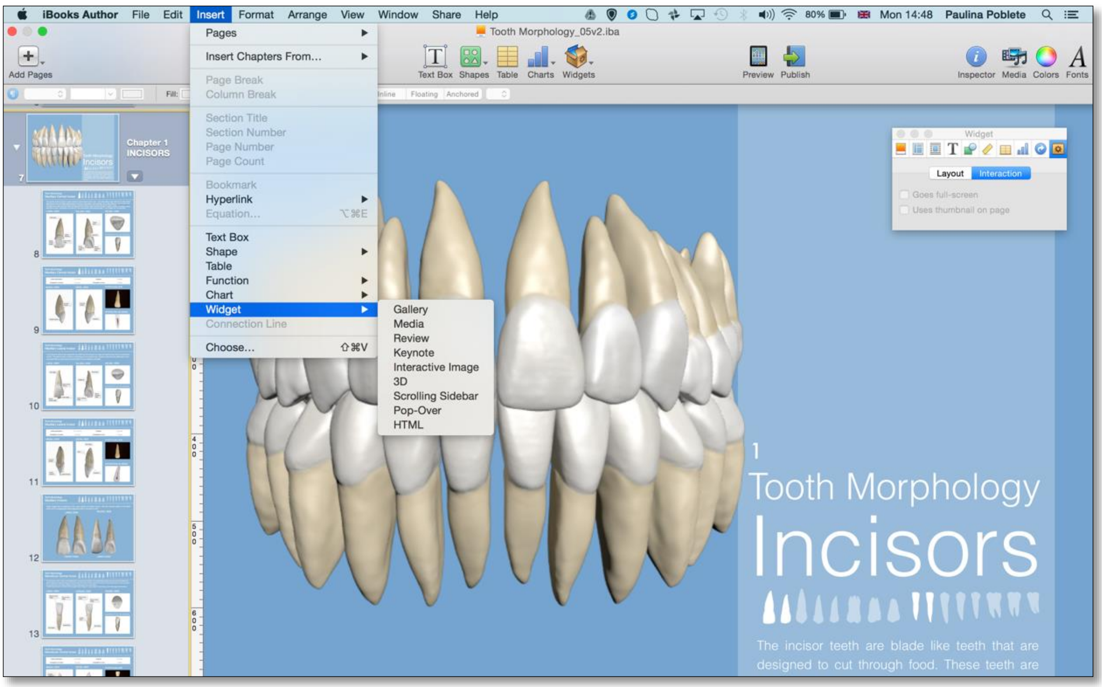


Figure 7.21: iBooks Author toolbar

The first step of the assembly process was to design a template for use in each chapter. The background colour and fonts were selected to ensure an appealing and modern look. Light-blue and white were the predominant colours. Once the researcher was pleased with the design the template was created using the tools of the authoring package. All elements were included in the iBook using the commands provided by the authoring package. Strategic captures of the 3D models were used to create interactive images, professional photographs were used to create the interactive galleries and the 3D models were included using a Collada file format to maintain its interactive features. Questions for the quiz section were also added using the corresponding command given by the software.

All sections were created following Kavadella et al.'s (2013) recommendation of using an introduction, chapters, and pages. As a result, the user had the option to jump from chapter to chapter or select a specific page of the iBook.

b) Testing

To ensure the correct functioning of the iBook in an iPad, the researcher exported the iBook from iBooks Author into a file compatible with iPad to test that all the properties worked correctly. One difficulty faced along the process was that whenever a Collada file was bigger than twenty megabytes the software crashed and the iBooks reader application stopped working. As a consequence, each file was carefully revised and modified to ensure that the size was within the limits. This process of reducing each file took the medical artist longer than expected as keeping the details and quality of the 3D models was a requirement. When the number of polygons of 3D models is reduced, and therefore the size of the file, details can be lost. Because it was important to produce 3D models as similar as possible to real teeth, it was crucial to balance between the file size and the amount of details preserved.

c) Quality assurance

The researcher and dental clinician involved in the project reviewed the 3D models to ensure that the major anatomical features and details were appropriate. Once the iBook was completed, the team involved in the process (main researcher, medical artist and dental clinician) revised the resource paying attention to the accuracy of the text, the aesthetics, quality of the photographs and functionality of the 3D models and interactive images.

7.4 THE FINAL RESULT

A multidisciplinary team worked together to produce the Tooth morphology iBook. The main features of the resource were the use of interactive galleries, interactive 3D Models, interactive images and concise factual text. The final resource had fifty-five pages that contained: thirty-two 3D interactive models, sixty-five interactive images, nine questions in the quiz section and sixteen galleries. The whole process of producing the iBook took more time than expected. To produce a good quality product, it took around six months to complete the resource, double the original planned time. Similar observations related with time and extra time needed to obtain a high-quality product were found by Farhat and Raven (2013). The resulting Tooth morphology iBook is unique, mainly because of its interactive features and the display method using an iPad. Other tooth morphology resources are described in the literature (Cantin et al., 2015; Mitov et al., 2010; Nagasawa et al., 2010; de

Boer et al., 2013; Mehl et al., 2005; Maggio et al., 2012); however, none of them is similar to the Dundee Tooth Morphology iBook. A full PDF version of the Tooth morphology iBook can be seen in Appendix 6.

8 DENTAL STUDENTS' PERCEPTIONS OF AN iBOOK ABOUT TOOTH MORPHOLOGY

8.1 INTRODUCTION

This chapter starts by reviewing information from previous studies that explored user perceptions and the use of iBooks in education. Then, the researcher presents the methodology and the results of this study.

Previous chapters in this doctorate project demonstrated that iBooks and iBooks Author are an easy, but time consuming, way to create high-quality learning tools, which can include 3D virtual models. However, the perception of users and their reactions to the resource were needed to obtain a complete evaluation of the use of iBooks and the 3D models.

The need for this study arises from the limited evidence available addressing iBooks users' perceptions. Few studies have explored user perception in relation to iBooks (Baena-Extremera and Granero-Gallegos, 2013; Thomas et al., 2013; Marei and Wajid, 2013; Chew et al., 2013). However, participants of two of those studies did not have a hands-on interaction with the device (Baena-Extremera and Granero-Gallegos, 2013; Thomas et al., 2013), and only one study had connections with dentistry (Marei and Wajid, 2013). None of the studies conducted a user perception analysis deep enough to inform and guide the construction of future prototypes.

The purpose of this study was to obtain students' feedback on an iBook addressing tooth morphology to inform and guide the development of future interactive iBooks for dental education. Therefore, the current study intended to determine if the design and features of the iBook met the users' expectations. The secondary aims were to compare the perceptions of two groups of dental students from different universities and identify any gender differences.

The research questions used in this study were:

- What are dental student perceptions of an iBook about Tooth Morphology?
- Are these perceptions similar across students from two different Universities?
- Are results affected by gender?

8.2 METHODOLOGY

A multidisciplinary team developed an iBook about Tooth Morphology and the content was validated by the lead academic in the subject at the Dundee Dental School (further details in Chapter seven). In brief, the iBook described the anatomical characteristics of all permanent teeth using interactive elements, formative quizzes, 3-D interactive models and multimedia tools.

The researcher used a mixed method approach including a questionnaire and a focus group session. Both methods are presented in separate sections.

8.2.1 ETHICS

This study received clearance from the University of Dundee Ethical Committee (UREC: 14173 – Appendix 11) and was frame-worked under the Helsinki Ethical document (WMA, 2008).

The researcher had no prior relationship with the participants, so no ethical concerns were perceived. Detailed and accurate information was provided and participation was voluntary. Participants had the right to withdraw at any time and were asked to give written informed consent. The researcher collected data anonymously and it was stored securely. Information sheets and consent forms provided were similar to the ones used in previous stages of this research and are exhibited in Appendix 2 and 3.

8.3 SECTION 1: QUESTIONNAIRE INTERVENTION

8.3.1 QUESTIONNAIRE

Several studies in medical and dental education have used questionnaires to investigate user perceptions (Hu et al., 2010; Salajan et al., 2009; Vuchkova et al., 2011; Prinz et al., 2005; Wright and Hendricson, 2010; Mitov et al., 2010; Hariri et al., 2004; Keller and Cernerud, 2002). They have also been used to investigate academics and students perceptions towards the use of iBooks (Thomas et al., 2013; Baena-Extremera and Granero-Gallegos, 2013). It was therefore thought appropriate to use a questionnaire for this study.

8.3.2 SAMPLE

The target participants were dental students from the University of Dundee and the University of The Andes (Chile) and the researcher applied a convenience sample strategy. Both dental schools took part in previous stages of this project, so authorities were familiar with the overall plan. The selection criteria were that participants had: formal instruction in tooth morphology completed before the intervention, little or no instruction in tooth preparation and no previous contact with the Tooth morphology iBook. First-year students from the University of Dundee and second-year students from the Andes University were invited as they met the proposed criteria. Second-year Chilean participants were starting their academic year and considered equivalent to Scottish first-year students who were finishing their first academic year.

8.3.3 INTERVENTION

Due to practicalities, intervention in both groups varied slightly. At the University of Dundee, the questionnaire was given during a practical session where the researcher divided the class into two groups. The length of the session was approximately 120 minutes. During the practical, half of the students had access to an iPad containing the Tooth morphology iBook. The other half had access to plastic tooth models and their traditional hand-outs. In total, eighteen iPads were used with thirty-six students. All students were encouraged to self-learn and to use their learning material. Students who had the iPads could also use the plastic models or their hand-outs to support their revision if they wanted to. Two clinicians and one lab technician were available during the session to answers questions. At the end of the first half of the session, the learning material was swapped between the two groups. Before ending the session, the researcher gave out the questionnaire and invited students to take part voluntarily. The researcher collected the completed questionnaires at the end of the session, as well as the written informed consents.

For the intervention with the Chilean participants the researcher, who is a Spanish native speaker, translated all documentation and the iBook into Spanish. Students were asked to bring their personal iPads on the day of the intervention as the University did not have the required number of devices. If a student did not have a mobile device, they were asked to work in pairs. However, each student received an individual questionnaire. The researcher installed the Spanish version of the iBook in each device before the session. The intervention started with a brief explanation of how to use the device and a presentation of the aims of the study. During the session, an assistant helped the main researcher to aid students and answer their questions. Students had thirty minutes to self-learn with the tablet before receiving the questionnaire. The complete intervention lasted approximately forty-five minutes.

8.3.4 THE QUESTIONNAIRE

The questionnaire was developed by modifying relevant questions extracted from previous studies with similar objectives (Hu et al., 2010; Salajan et al., 2009; Vuchkova et al., 2011; Prinz et al., 2005; Wright and Hendricson, 2010; Mitov et al., 2010; Hariri et al., 2004; Keller and Cernerud, 2002). The researcher established three categories: “Learning process,” “Content” and “Design-Interactivity.” Sixteen questions were developed using a five-point Likert scale. Nine questions focussed on the learning process, three on content and four addressed the design of the tool and the interactive three-dimensional elements. The questionnaire also included an open question for additional feedback. Declaration of gender was the only demographic detail requested for comparison purposes. The supervisors of this project considered experts in the field, reviewed the questionnaire to enhance content validity. Before the intervention, face validity was sought by asking five postgraduate dental students to validate the language and accuracy of the questions. The questionnaire was pilot tested by a small group of postgraduate dental students to ensure the questions were clear and fair. An extract from the questionnaire is shown in Figure 8.1 and the complete instrument is in Appendix 7.

• The Tooth Morphology iBook •

Please choose the best answer for each of the following statements

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
The iBook was easy to use	○	○	○	○	○
The layout was well designed	○	○	○	○	○
The use of the iBook didn't really facilitated my learning	○	○	○	○	○
This teaching method motivates me to learn	○	○	○	○	○
The volume of information in 3D was appropriate	○	○	○	○	○
I am satisfied with the 360 degree rotation models	○	○	○	○	○
The 3D content was of poor quality	○	○	○	○	○
I have enjoyed learning Tooth Morphology with the 3D interactive iBook	○	○	○	○	○
In future, I would prefer to learn other areas of Dentistry with the 3D interactive iBook rather than with a textbook	○	○	○	○	○
I really liked the iBook's user interface	○	○	○	○	○

Figure 8.1 Extract of the questionnaire used in this study

8.3.5 RESULTS OF THE QUESTIONNAIRE AND STATISTICAL ANALYSIS

Fifty-six first-year dental students from the University of Dundee participated from a year group of 72 students (77.8%). One participant completed half of the questionnaire: nevertheless, those clearly stated answers were considered in the data analysis. From the fifty-six questionnaires, thirty-two were completed by females and twenty-three by males.

From the Chilean cohort, eighty-two out of a year group of 88 (93.1%) participants took part, fifty-nine females and twenty-one males. Four questionnaires were incomplete; however, the analysis included clear stated responses.

In total 138 students contributed to the study. The collected data was arranged per question (Table 8.1). The first statistical analysis compared responses from Scottish and Chilean participants using a Mann-Whitney U test, revealing significant statistical significance ($p \leq 0.05$) in seven of the statements. These are identified by an * in Table 8.1. The statements that did not show a significant difference were number 1, 2, 6, 7, 10, 11, 12, 14, 15. From these, it was observed that most participants strongly agreed that the resource was easy to use (Statement 1). They also strongly agreed that the resource was well designed (Statement 2). Statement 6 indicated that the majority of participants either agree or strongly agree that they were satisfied with the 360-degree models, responses that correlate with the ones observed in statement 7 were most participants disagree or strongly disagree with "The 3D content was of poor quality". When asked if they liked the interphase (Statement 10), positive results were obtained, as most students either agree or strongly agree to it. With regards to statement 11, which asked if this resource should be available to every student, the vast majority of participants in both groups indicated that they strongly agreed. However, this consensus in the responses was not observed in statement 12: “Learning Tooth Morphology seems easier with a textbook book rather than with the iBook” and statement 15: “The iBook provided material that was not otherwise available to me.” In both cases, participants stated preferences across the five possible answers. When students were asked if the iBook should replace traditional lectures (Statement 14), most participants either felt dubious, disagreed or strongly disagreed; showing that lectures are still not to be replaced by this technology.

From those responses that showed a significant statistical difference between groups, the results suggest that the Chilean participants were more positive in some of the statements. Fifty six per cent of the Chilean sample strongly agreed to the statement 4 “This teaching method motivates me to learn” compared to only 13% of the Scottish participants. Similar rates were observed for the statements number 5 and 8. When participants were asked if “The use of the iBook didn't really facilitate my learning” (Statement 3) 13 % of the Scottish participants strongly disagreed and 67% disagreed with the statement, and 40% of the Chileans strongly disagree and 33% disagree. More strongly agree responses were collected from Chilean participants (60%) than the Scottish (29%) for the item: “In future, I would prefer to learn other areas of Dentistry with the 3D interactive iBook rather than with a textbook” (Statement 9). When asked about their confidence after using the resource, 52% of the Scottish individuals agreed or strongly agreed with the statement 13 “I feel more confident learning with an iBook than with a textbook” while only 7% disagree or strongly disagree with the statement. However, 36% of the Chilean participants agree or strongly agree and 14% disagree or strongly disagree when asked about their confidence gain. The final significant statistical difference was observed ($p<0.5$) when participants were asked if they felt the iBook was of little help for the practical exam preparation (Statement 16), in this case, most participants in both groups disagree with the statement (Scottish= 55%, Chilean= 49%).

The main findings showed that the Tooth morphology iBook was easy to use, and that it motivated students to learn and that the resource should be available for every student. Also, participants recognised the quality of the 3D models and appreciated the number of 3Ds provided. Students were more equivocal when asked if iBooks should replace traditional lectures or if the iBook provided material that they did not have access too. Most participants stated that the iBook did contribute to their tooth morphology practical preparation.

Table 8.1: Frequencies obtained per statement; Scots in blue and Chileans in red.

Statement	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	No Answer
1. The iBook was easy to use	0(0%) 1(1%)	0(0%) 0(0%)	1(2%) 2(2%)	23(41%) 21(26%)	32(57%) 54(66%)	0(0%) 4(5%)
2. The layout was well designed	0(0%) 0(0%)	0(0%) 1(1%)	1(2%) 3(4%)	27(48%) 28(34%)	28(50%) 44(54%)	0(0%) 6(7%)
*3. The use of the iBook didn't really facilitated my learning	7(13%) 40(49%)	37(67%) 27(33%)	6(11%) 6(7%)	4(7%) 1(1%)	1(2%) 4(5%)	1(2%) 4(5%)
*4. This teaching method motivates me to learn	0(0%) 0(0%)	3(5%) 1(1%)	15(27%) 2(2%)	30(55%) 31(38%)	7(13%) 46(56%)	1(2%) 2(2%)
*5. The volume of information in 3D was appropriate	0(0%) 0(0%)	5(9%) 0(0%)	2(4%) 2(2%)	28(50%) 35(43%)	21(38%) 42(51%)	0(0%) 3(4%)
6. I am satisfied with the 360 degree rotation models	0(0%) 0(0%)	1(2%) 1(1%)	6(11%) 5(6%)	23(43%) 28(34%)	24(44%) 46(56%)	2(4%) 2(2%)
7. The 3D content was of poor quality	21(38%) 36(44%)	27(48%) 34(41%)	5(9%) 4(5%)	3(5%) 4(5%)	0(0%) 0(0%)	0(0%) 4(5%)
*8. I have enjoyed learning tooth morphology with the 3D interactive models	0(0%) 0(0%)	2(4%) 0(0%)	4(7%) 4(5%)	37(66%) 36(44%)	13(23%) 40(49%)	0(0%) 2(2%)
*9. In future, I would prefer to learn other areas of Dentistry with the 3D interactive iBook rather than with a textbook	1(2%) 0(0%)	2(4%) 0(0%)	13(23%) 6(7%)	24(43%) 25(30%)	16(29%) 49(60%)	0(0%) 2(2%)
10. I really liked the iBook's user interface	0(0%) 0(0%)	0(0%) 1(1%)	3(5%) 10(12%)	38(68%) 39(48%)	15(27%) 30(37%)	0(0%) 2(2%)
11. The iBook should be made available for all dental students to learn tooth morphology	0(0%) 0(0%)	0(0%) 1(1%)	1(2%) 1(1%)	15(27%) 12(15%)	39(71%) 66(80%)	1(2%) 2(2%)
12. Learning Tooth Morphology seems easier with a textbook book rather than with the iBook	10(18%) 17(21%)	16(29%) 29(35%)	20(36%) 14(17%)	8(15%) 9(11%)	1(2%) 11(13%)	1(2%) 2(2%)
*13. I feel more confident learning with iBook than with a textbook	0(0%) 2(2%)	4(7%) 10(12%)	19(35%) 38(46%)	20(36%) 16(20%)	12(22%) 13(16%)	1(2%) 3(4%)
14. I would prefer if lectures were replaced by iBook	9(16%) 16(20%)	22(40%) 16(20%)	17(31%) 30(37%)	5(9%) 9(11%)	2(4%) 9(11%)	1(2%) 2(2%)
15. The iBook provided material that was not otherwise available to me	3(5%) 11(13%)	16(29%) 20(24%)	17(31%) 19(23%)	13(24%) 16(20%)	6(11%) 13(16%)	1(2%) 3(4%)
*16. I feel the iBook was of little help for the practical exam preparation	8(15%) 25(30%)	30(55%) 40(49%)	9(16%) 10(12%)	8(15%) 4(5%)	0(0%) 0(0%)	1(2%) 3(4%)

The third statistical analysis (Wilcoxon rank sum test with continuity correction) compared the median scores of males and females and also the median scores of Scottish and the Chilean participants. Both analyses gave non-significant (p values of 0.8 and 0.5 correspondingly) showing that participants shared the same views. Table 8.2 the medians scores for both groups compared.

Table 8.2: Median scores for Females and Males, and Median scores for Scottish and Chilean participants

Statement	Females	Males	Scottish	Chilean
1. The iBook was easy to use	5	5	5	5
2. The layout was well designed	5	4	4	5
3. The use of the iBook didn't really facilitated my learning	2	2	2	2
4. This teaching method motivates me to learn	4	4	4	5
5. The volume of information in 3D was appropriate	5	4	4	5
6. I am satisfied with the 360 degree rotation models	5	4	4	4
7. The 3D content was of poor quality	1	2	2	2
8. I have enjoyed learning Tooth Morphology with the 3D interactive	4	4	4	4
9. In future, I would prefer to learn other areas of Dentistry with the 3D interactive iBook rather than with a textbook	4	4	4	5
10. I really liked the iBook's user interface	4	4	4	4
11. iBook should be made available for all dental students to learn Tooth Morphology	5	5	5	5
12. Learning Tooth Morphology seems easier with a textbook book rather than with the iBook	2	3	2	3
13. I feel more confident learning with iBook than with a textbook	3	4	4	3
14. I would prefer if lectures were replaced by iBook	3	3	2	3
15. The iBook provided material that was not otherwise available to me	3	3	3	3
16. I feel the iBook was of little help for the practical exam preparation	2	2	2	2

8.4 SECTION 2: FOCUS GROUP

8.4.1 METHODOLOGY

In this section, the decision was to use the Hermeneutic Phenomenology methodology described by van Manen (1997) because it brings together the interpretative essence of the hermeneutic method and also the descriptive essence of the phenomenological method. Hermeneutic Phenomenology allows the researcher to use their background in favour of data analysis and data collection (Sloan and Bowe, 2014). Also, it was decided to use Grounded Theory because it allows the use of a coding technique which permits concepts to emerge from the data (Holton et al., 2007). Triangulation of these two theories has been used successfully in nursing to provide a deep insight into the understanding of a phenomenon (Annells, 2006; Wilson and Hutchinson, 1991). The use of these approaches allows the researcher to have an active role in the data collection and the analytical process.

The selected method was to use a semi-structured focus group using an audio record followed by a transcript and coding of data. After the results of the questionnaire were analysed, students from the University of Dundee were invited to a focus group session. At this point, the researcher did not include students from the Andes University as setting-up an online focus group was not possible.

The semi-structured focus group was arranged based on the guidelines described by Krueger (2009). In general terms, the aim was to invite volunteers to discuss their experiences of using the iBook openly and, discuss the results of the questionnaire. The researcher organised a lunch gathering at the Dundee Dental School providing food and drinks in an informal setting.

8.4.2 SAMPLE SELECTION

The target participants were students who took part in the practical intervention and who were willing to talk about their experience with the new device. Therefore, a purposive sampling technique was used, aligned with the methodological framework selected.

8.4.3 RECRUITMENT

The researcher approached students in one of their lectures inviting them to take part in the focus group providing information about the study verbally. Volunteers were asked to give their contact details to arrange a suitable time and date. Then, an email with further details and complete information about what to expect in the focus group was sent to participants. In total, six students agreed to take part in the study. However, due to personal reasons two were unable to participate.

Management of ethical issues followed the same principles explained in the Ethics section; this included providing full information and the chance to withdraw at any time. As the focus group required an audio recording anonymity was guaranteed. Consent was given verbally and in a written form before beginning the discussion.

8.4.4 DATA COLLECTION

The researcher used a double recording method to ensure no data was lost due to technical issues. A professional audio recorder Olympus Model VN-713PC and a MacBook Pro were used. As suggested by Laverty (2003) to comply with the hermeneutic phenomenology, the researcher had a dynamic role in the data collection encouraging participants actively to recall their experiences in as much detail as possible. The researcher then transcribed the audio record in detail including verbal and non-verbal expressions. This technique included laughter and the expressions of participants. The interpretation of gestures, silences, and laughter, is aligned with the methodology selected. Some authors believe that this kind of transcripts provides a richer insight into the data (Bailey, 2008). The transcription process permitted familiarisation and an efficient interpretation of data, which elevated the rigour of the data analysis process (Seale and Silverman, 1997).

Additionally, responses given to the open question in the questionnaire were included in the qualitative analysis. These responses were collected from both groups (Scottish and Chilean) and transcribed to a new document to facilitate analysis.

8.4.5 QUALITATIVE DATA ANALYSIS AND CODING PROCESS

For the data analysis, a triangulation between hermeneutic phenomenology and grounded theory was applied to ensure rigour in the analytical process. Both transcripts were coded using a computer-assisted qualitative data analysis software; NVivo11. A computer-based technique was selected as it can facilitate the procedure (Holloway and Wheeler, 2013), easing the analysis and speeding the coding process. The process was completed by the researcher re-reading the transcripts and interpreting the participants' views.

The coding process allowed data to emerge by using grounded theory (Holton et al., 2007). Six themes emerged from the responses: Device, 3D models, Interactivity, Learning, Content and Generalities of the iBook. In the first coding round the data was divided into four categories: positive comments, negative comments, suggestions and reflective comments. Then a second coding was conducted which classified data into the identified themes. Intra-rater reliability was used to ensure rigor of the coding process.

8.4.6 RESULTS

In total sixteen negative comments were received, thirty-eight positive, thirty-seven suggestions and twenty-seven reflections. The distribution of the observations varied depending on the category. Most of the positive observations and reflective comments were related to learning and how the tool simplified the process. Four of the negative comments addressed the quality of the 3D models and four commented on how the tool is not ideal to replace traditional learning methods. As expected, most suggestions were associated with the content, indicating the need of further information and features. A summary of the results is shown in Tables 8.3 to 8.8. Each table represents the number of comments obtained per category plus the core idea of the statements collected.

Table 8.3 shows the results concerning the “Device”. Participants believed that iPads were easy to use yet there was a concern about the limited access to these devices. Some participants suggested that the iBook should be compatible with other types of tablet as well. In the focus group, students were asked if they would like the University to provide iPads to facilitate their studies and all participants strongly agreed.

Table 8.3: Summary table of comments obtained about the Device used.

Type	Number	Core idea
Negative	2	Many students do not have iPads
Positive	2	This technology is easy to use
Suggestion	2	This technology should be available for other tablets too.
Reflection	4	Students would like to have access to an iPad for their studies

Concerning the "Content", three negative comments were obtained; two indicating that the content was too basic while the other expressed that information was too broad. Positive observations stated that the information was complete and adequate. Suggestions were about the addition of new features and extra information. When asked if further information would make the iBook too comprehensive, one student mentioned that *"If you say that, you could not be doing dentistry."* This information is summarised in Table 8.4.

Table 8.4: Summary table of comments obtained about the Content of the iBook.

Type	Number	Core idea
Negative	3	For some information was too basic, whereas for other it was too broad.
Positive	3	Information was adequate and complete.
Suggestion	17	New features. Among the most recurrent ones were the inclusion of the Carabelli cusp, deciduous teeth and more questions in the quiz section. More detailed information and more examples of real teeth including its variations.
Reflection	1	Students preferred comprehensive content.

Table 8.5 presents feedback about the "3D models" contained in the iBook. Four out of the sixteen overall negative statements were about the 3D models. These remarked on the quality, as some expected more detail and higher specifications in the models. However, there were twice as many positive comments. The reaction

of students towards the features of the iBook indicated that the prototype was of high-quality. Suggestions included having more 3D models in the quiz section and adding further details in the 3D models. Overall, the reflection section pointed out that the 3D models were satisfactory.

Table 8.5: Summary table of comments obtained from the 3D models.

Type	Number	Core idea
Negative	4	Most comments criticise the quality of the 3D models in terms of details and specifications
Positive	8	The quality of the 3D models
Suggestion	5	Participants would like further details in the 3D models and more use of those in the quiz section
Reflection	2	Reflections point out that the 3D models are good as they are

As shown in Table 8.6, commentaries obtained about the iBook were mostly positive, showing that students would like to have this type of technology available. A few of the negative comments related to the slowness of the device.

Table 8.6: Summary table of general observations obtained about the iBook

Type	Number	Core idea
Negative	3	Some iBooks were slow while operating
Positive	7	Majority of comments make evident that participants want the iBook
Suggestion	1	The iBook should exist for Android
Reflection	0	

The participants provided no negative comments related to the “Interactivity” of the resource. The use of the iBook offered a new experience. Four out of the five comments advocated the inclusion of videos in the iBook (Table 8.7).

Table 8.7: Summary table of comments obtained about Interactivity.

Type	Number	Core idea
Negative	0	
Positive	5	Students valued the interactive features as positive and unique.
Suggestion	5	Participants strongly suggested the addition of videos and links.
Reflection	5	The experience and the feeling when using the iBook was considered a positive feature. Participants found the delivery format exciting.

Table 8.8 presents the comments related to "Learning". Overall participants believed this tool could effectively facilitate learning as they can access it from outside the Dental School. However, negative comments indicated that using only an iBook is not enough for learning. Participants suggested that the iBook could include further feedback features and more questions in the quiz section.

Table 8.8: Summary table of comments obtained about Learning.

Type	Number	Core idea
Negative	4	Learning only with the iBook is not ideal as assessment includes real teeth and lectures offer further details
Positive	13	Benefits of the use of the iBook for learning; are to supplement, support, revise and aid practical classes are disclosed by participants.
Suggestion	7	Most suggestions directed to the addition of further quiz questions with detailed feedback.
Reflection	15	Participants identify the practicality of learning with an iBook, which can serve as a revision material outside the dental school. Also, it was identified that it that can be used to increase confidence in their learning. Again, participants mentioned that the iBook complements their learning but is insufficient on its own.

8.5 DISCUSSION

The results suggest that students enjoyed the Tooth Morphology iBook and that it aided their learning. Students indicated that the iBook was easy to use, motivated learning, and should be available for every learner. Most of the participants stated that this technology facilitates learning more than a textbook.

For the minority of participants, this experience was not of value regarding making learning easier compared to a textbook. Most participants felt that lectures should not be replaced by this kind of learning tool. The results of this study are aligned with the findings presented by Murphy et al. (2004). These authors analysed dental students' learning preferences. Two hundred and twenty-eight participants from Temple University, USA were asked to complete a VARK survey. (VARK, stands for Visual, Aural, Read/Write, and Kinesthetic which is a survey created in 1998 by Neil Fleming aiming to facilitate communication between students and educators (Murphy et al., 2004)). The results revealed that dental students, especially junior ones, preferred instruction through lectures and visual materials. The fact that the Tooth morphology iBook is a highly visual tool could be the reason underpinning the positive attitude that students demonstrated towards the resource. The results are also aligned with Kevan (2013) findings as the resource was enjoyable and well accepted by students.

The statistical analysis revealed that there was no median difference between students from Dundee University and The Andes University. These results suggest that regardless of the idiomatic difference and the geographic distance between the two groups, students were similar in the way they perceived the use of the iBook. When the questions were analysed individually, some statements showed statistical differences. However, rather than a total disagreement in the responses of the participants, it was observed that the difference was in terms of the intensity of the responses. Despite the statistical difference in seven of the statements the researcher considered that the results of both groups were similar. Analysis of the median results of females and males demonstrated no statistical difference when gender was analysed.

After the analysis of qualitative data, it was confirmed that students liked the iBook as a learning resource. Comments were mostly positive, and no rejection towards its use was perceived. No student indicated that they would not use the learning resource. On the contrary, some commentaries were very enthusiastic and positive such as: “Cool app” or “I really liked the 3D models”. These responses align with the strong agreement observed in question eleven which stated that the iBook should be available for every student to learn tooth morphology.

Interestingly, some students felt that the content was too detailed while others wanted more information. This discrepancy might be a result of how students want to use the learning tool. Perhaps some would like to use it as a revision instrument while others want it as a primary material guide for their studies. This difference might have some connection with the learning styles preferred by the students. Different learning styles impact on the type of learning material someone wishes to use (Honey et al., 1992). Nevertheless, students’ positive views towards the utilisation of the iBook as a learning tool were clear. On the other hand, there were reservations about it replacing traditional teaching methods: “It’s great for learning theory and supplements the actual real teeth well, but I couldn't just learn with the iBook." In a study by Martin et al. (2012), the authors compared the perceptions of students towards the use of technology for distance communication and face-to-face instruction. Students' perceived face-to-face learning as being more effective. These results support the declared intentions of participants of maintaining traditional methods for learning as well as accessing the iBook.

One of the recurrent suggestions was the amount of feedback provided by the quiz section. Students wanted more activities which involved feedback such as practical quizzes and detailed feedback to their answers. These comments are in line with results shown in a study which revealed that students want feedback when using technology for learning such as computer assisted learning (Rogers et al., 1998). Feedback has been recognised as one of the most important aspects of the learning process as it allows the learner to reflect and anchor knowledge more deeply (Perera et al., 2008; Mann et al., 2009; Swanwick et al., 2010; Mann, 2011).

Students evaluated the 3D models contained in the iBook positively. The questionnaire and the focus group revealed that students are keen to access this sort of material. For some, 3D models and the interactivity they offer were the most appealing features of the iBook, demonstrating that there is a need to enhance this type of technology in the future. The enthusiastic response from students towards the use of 3D models has also been observed in other studies. Vuchkova et al. (2011) observed similar perceptions of students about a 3D learning tool used for radiographic interpretation. Hu et al. (2010) also received positive comments from students when introducing a 3D model of the larynx.

Participants indicated that the 3D models were helpful to aid learning. However, they suggest that using 3D models for assessment purposes was not as helpful as using natural teeth. Some comments suggested changes to the 3D models, for example. “More 3D rotation models especially for the quiz section.”, “I hope there is more guidance in the left and right sides” and “further details in the 3D models”.

There were no negative comments about interactivity. Interactivity has proven to have a substantial effect on the learning process on other areas of dentistry (Salajan et al., 2009). In the iBook all pages contained some degree of interactivity, making the iBook more than just a regular e-book with text and images. The use of several visual elements was considered important by students and aligns with the findings of Murphy et al. (2004)

Students also appreciated the fact that the resource is a mobile tool. They suggested that the iBook could be used outside the dental school. Due to the confines of the study, the resources were tested inside the University and further details of how it enhances mobile learning were unexplored. However, the following statement “*…cos after a while you don’t want to keep coming to the dental school to look for questions. So, if you have them at home you can keep going through, and it’s much easier*” suggests that the iBook could have a positive impact when used outside the dental school or as a distance learning resource. Also, during the interventions, some students took photographs of the iBook, and when asked why, they stated they were going to use the photos to study later.

When asked directly about the potential of the resource for learning, students valued and recognised the usability of the tool. All questionnaire items related to learning had a positive response, information that the researcher then confirmed in the focus group. Terms like “confidence”, “motivation” and “support” were used in the focus group showing that the iBooks can have a positive effect on students’ learning. However, students made it clear that they want to keep their traditional teaching methods as they felt unsure about totally replacing conventional methods with the iBook. It seems that they are not keen on losing their theoretical, clinical or practical lessons, on the contrary, they want to supplement their current teaching methods with this type of technology. These results are in line with similar concerns revealed by students who took part in a study by Steele et al. (2002).

Suggestions to improve the resource included adding tags representing the sides of each tooth, however, this was not possible with the Collada files. Adding more feedback questions in the quiz section and the inclusion of videos were also among the requests of students. Fenwick Jr et al. (2013) provided iPads with an iBook to a group of computer science students. Eight students received an iPad whereas ten students were provided with a non-interactive PDF version of the material. The authors surveyed the students about the likes and dislikes of the iBook, revealing a strong preference for the use of videos. Despite the small size of the sample, these results are aligned with the desires of the users of the present study, were individuals recommended the addition of more instructional videos. The researcher shall consider these suggestions for future versions of this iBook.

The overall findings of this study suggest that the Tooth morphology iBook is an innovative and exciting learning material for dental students. Other authors have collected positive users perceptions about iBooks (Baena-Extremera and Granero-Gallegos, 2013; Fenwick Jr et al., 2013; Thomas et al., 2013; Chew et al., 2013; Marei and Wajid, 2013), however, this is the first study addressing dental students' perception focusing on the use of 3D interactive models included in an e-learning resource.

8.6 CONCLUSIONS

The final findings of this study show that the Tooth Morphology iBook was positively received by students, had clear potential for learning and teaching purposes; and could supplement traditional teaching methods but not replace them. Results suggest that this tool can serve in a novel way to present learning material using 3D material with which students can interact and learn. Further studies are required to determine if this type of resource has a long term positive impact on education.

9 THE DUNDEE TEMPOROMANDIBULAR JOINT IBOOK

9.1 INTRODUCTION

This chapter details the authoring process and creation of the Temporomandibular joint (TMJ) and masticatory system iBook. To ensure an appropriate design, the researcher applied the nine steps described by Gagne and Briggs (1974) to inform the authoring process and applied key e-learning principles as discussed in Chapter five. Also, the feedback collected from the users about the Tooth morphology iBook was used to improve the design and layout.

At the end of the chapter, the researcher details the authoring process of a 2D iBook version. This version was needed to compare it with the 3D one, an intervention which is detailed in Chapter ten.

The topic of this second iBook was based on the results obtained in Chapter three. Anatomy of the temporomandibular joint was the area of dentistry identified as the one that would benefit the most from the use of 3D interactive learning models. These results, plus the clinical importance of this joint, and the lack of 3D resources in the field justified the construction of the TMJ iBook. Chapter six addressed the importance of the TMJ providing further evidence of why this was the ideal topic.

At Dundee Dental School the anatomy of the TMJ is taught using traditional methods, based on lectures using PowerPoint presentations. Practical sessions include anatomical dissections and the use of skull bones and plastic models. However, there are no digital resources available to help students with the learning of this complex joint. Considering this information, it seemed that an e-learning resource addressing the TMJ using interactive 3D models could help students with their learning. However, evidence is needed to support this statement. To obtain this information an experimental study was designed (Chapter ten) where two almost identical iBooks were compared. Therefore, two iBooks were authored; one containing 3D models and another one containing 2D images.

9.2 STEPS FOR INSTRUCTIONAL DESIGN OF THE TMJ IBOOK

STEP 1: GAINING ATTENTION

To get users attention, the researcher applied the same strategy as in the Tooth morphology iBook. An open question emphasised why it was important to study the anatomy of the TMJ. The question introduced three main aspects why anatomical features of this joint are important for dentistry (Figure 9.1). In the introductory section, no interactive images were used as the user could decide not to activate the pop-up of the interactive images and not receive the information. Therefore, the researcher preferred to avoid the interactive images and provide the information in a text box attached to a still image.

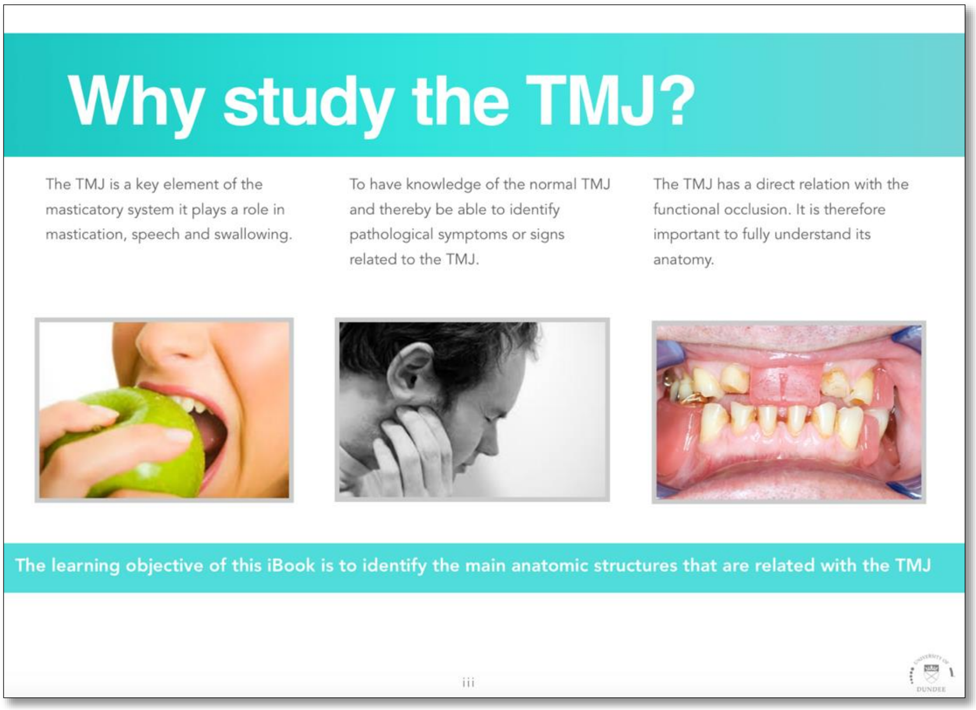


Figure 9.1: Introduction page of the TMJ and masticatory system iBook

STEP 2: INFORMING LEARNER OF OBJECTIVES

The introductory page contained the learning objective using a highlighted text box (Figure 9.2). Providing the learning objective and showing the importance of learning about the TMJ, aimed to attract students' attention, and invite them to explore the rest of the resource.

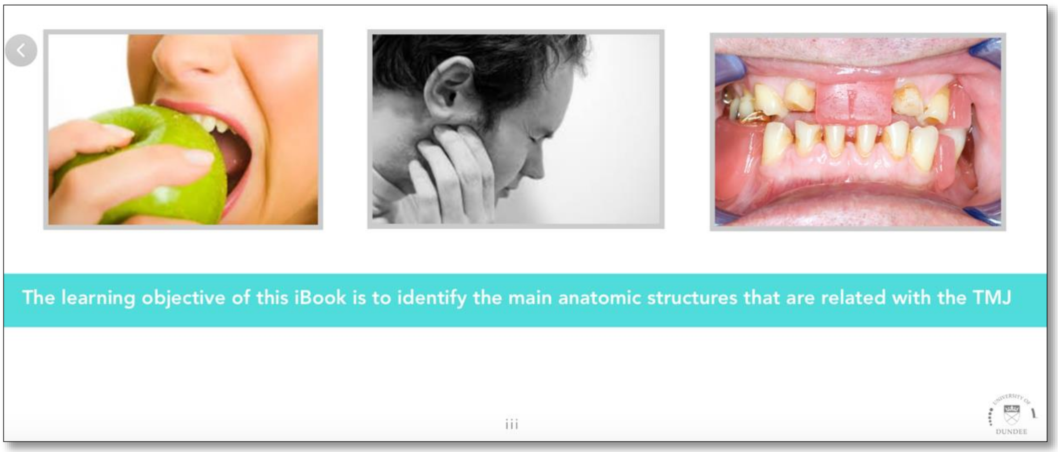


Figure 9.2: Learning objective of the iBook

STEP 3: STIMULATE RECALL OF PRIOR LEARNING

Each chapter began with a brief introduction of the topic. This strategy announced the content to students and helped them recall their past knowledge about the subject. Each introductory page contained factual information of the structure and a 3D interactive model (Figure 9.3).

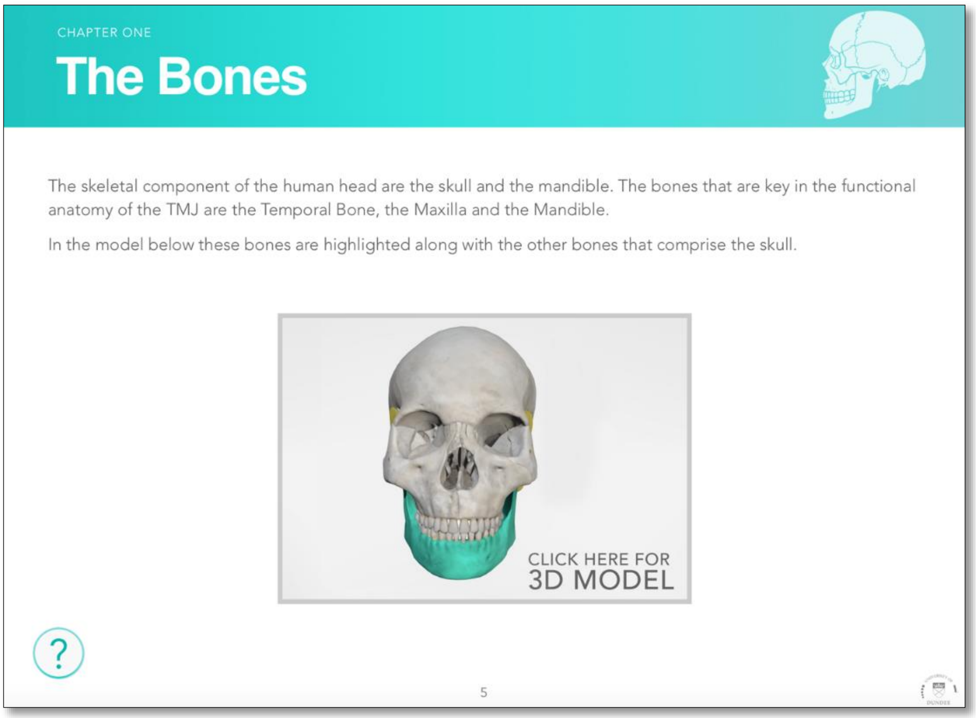


Figure 9.3: Example of introduction page of Bone chapter

STEP 4: PRESENTING THE CONTENT OR STIMULUS MATERIAL

The TMJ iBook followed a similar structure to the Tooth Morphology iBook, using chapters. The content contained text boxes, 3D interactive models, videos and photo galleries. The 3D interactive models gave the user the chance to explore, interact and manipulate each structure detailed in the iBook. In this iBook, the 3D interactive models did not use a Collada file format because most models exceeded 20 megabytes and it was not possible to achieve a reduction of the files without compromising their quality. The format used to display the 3D models were hypertext markup language (HTML) links that the user could click and access an Internet site: Sketchfab) directly from the iBook. Among the benefits of using Sketchfab over Collada files is that the platform allows adding tags and manipulate animated 3D models. Further details about the use and properties of Sketchfab are described in section 9.3.1."a" of this chapter. The HTML links allowed a proper size of the file without jeopardising the complexity and details of the 3D models. Moreover, the HTML format permitted the inclusion of programmed movements and tags to the models, features that were not possible with the Collada files.

In the TMJ iBook, the HTML links were incorporated and represented by an image of the original model that invited the user to "click" the image. This strategy enabled a uniformity to be maintained. Figures 9.4 and 9.5 show the link provided to access an interactive 3D model before and after its activation.

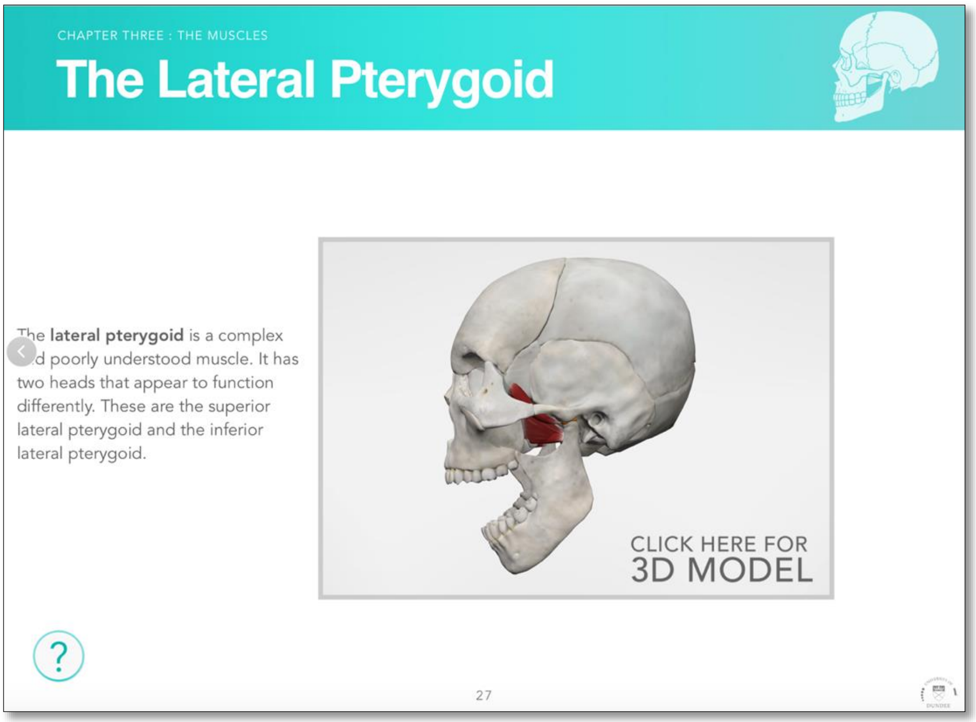


Figure 9.4: 3D interactive model link before activation

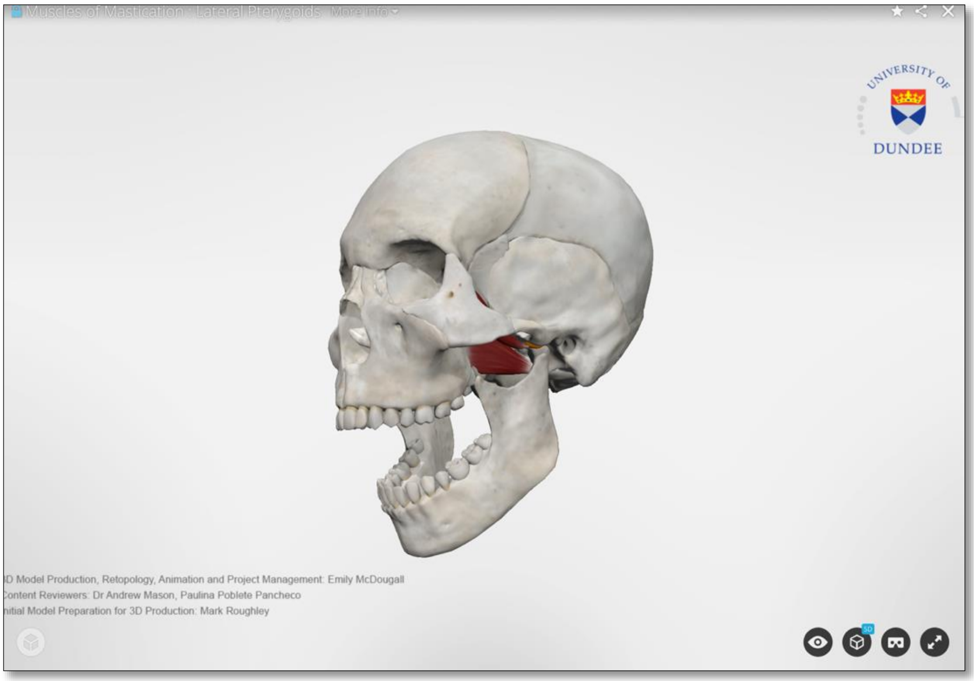


Figure 9.5: Interactive 3D model opened in Sketchfab

Another item included in the iBook was the interactive galleries, containing professional photographs taken by the Dundee Dental School clinical photographer (Figure 9.6). The formula of using a black background provided an attractive look in the previous iBook, so the strategy was repeated in this new prototype.

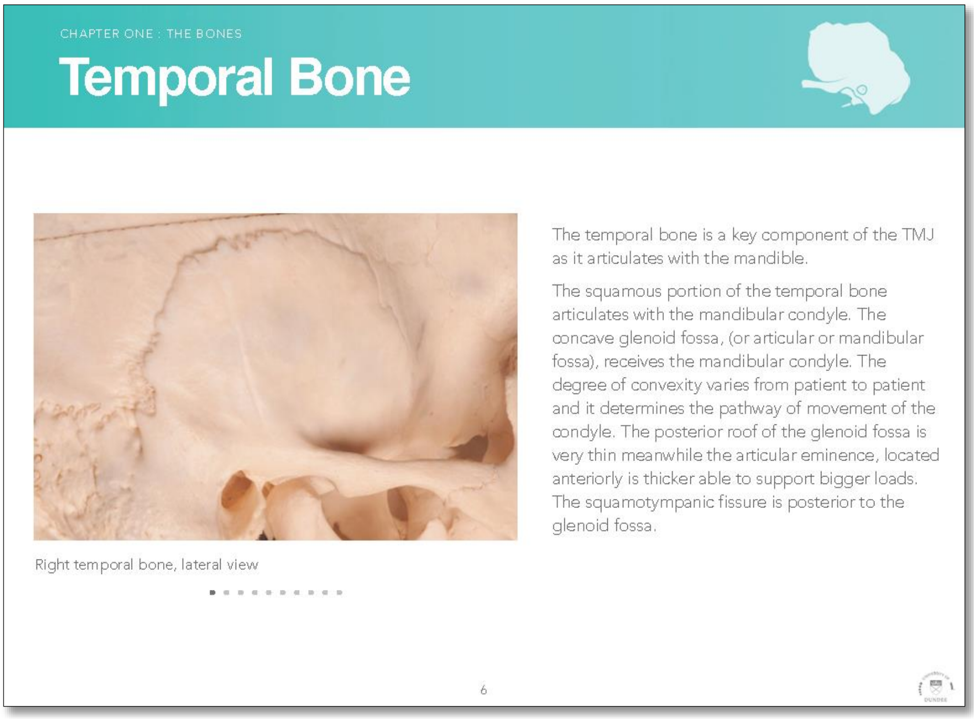


Figure 9.6: Example of the interactive galleries and content distribution

STEP 5: PROVIDING LEARNING GUIDANCE

Keeping a consistent and well organised layout for all stages of the learning tool helped guide the students through the module. The Tooth morphology iBook had a video with instructions; however, the researcher noticed that most of the students did not use the audio-visual during the intervention. As an alternative, the second page of the TMJ iBook contained a series of gesture icons which explained how to use the resource. This interactive and informative option aimed to ensure that the user did not miss any of the iBook’s capabilities. The gesture icons used are shown in Figure 9.7.

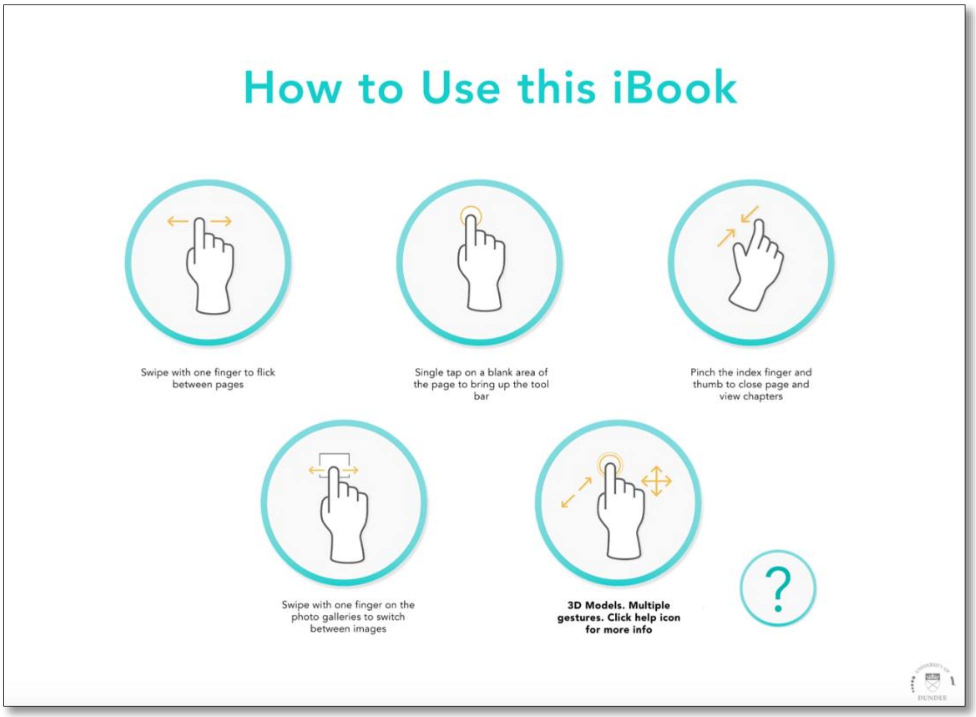


Figure 9.7: Instructions provided in the iBook using gesture icons

Additionally, all pages containing an HTML link had a question mark symbol which displayed a pop-up reminder of how to use the 3D models (Figure 9.8).

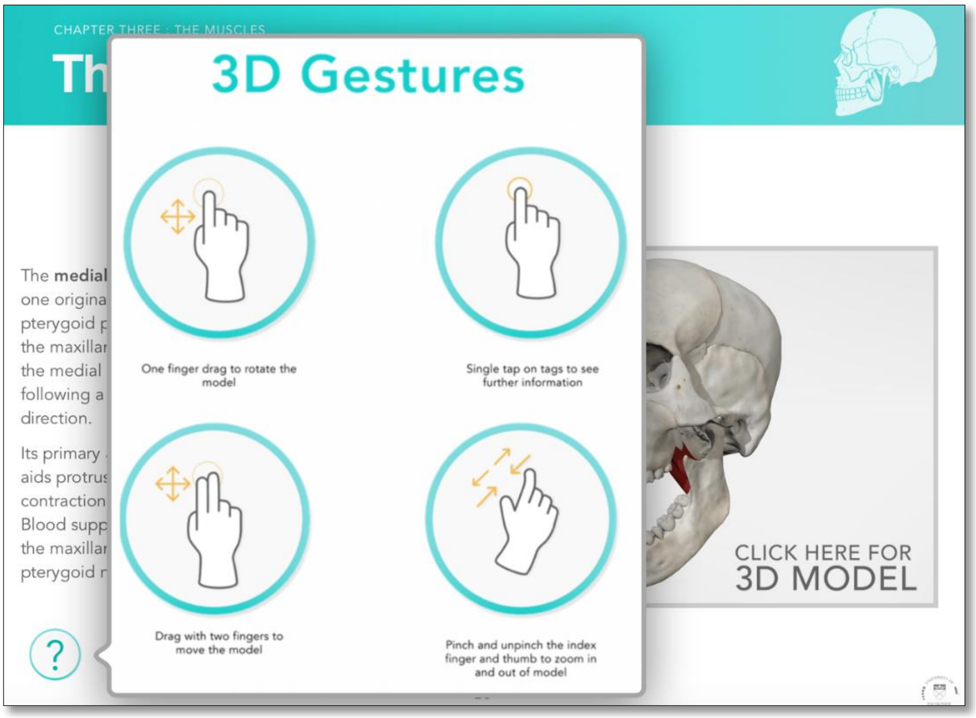


Figure 9.8: Instructive pop up for guiding students

STEP 6: ELICITING PERFORMANCE

To ensure practice each chapter had a review page at the end containing multiple choice and drag and drop questions. An example is shown in Figure 9.9. Screen captures of coloured 3D models were used to ask students precision questions about different features of the structures.

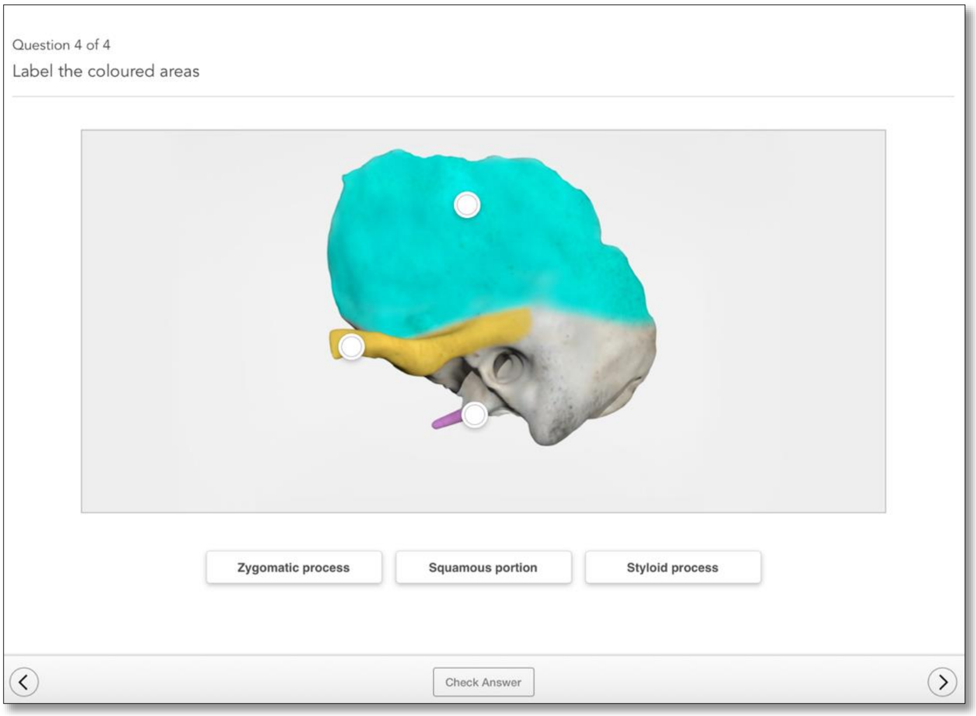


Figure 9.9: Example of a quiz section page displaying a drag and drop question

STEP 7: PROVIDING FEEDBACK

The researcher recognised the importance of formative feedback as well as constructive and positive feedback (Perera et al., 2008). However, the choice was not to provide extended feedback in this iBook to avoid making the resource too long for the experimental purpose. However, each question contained immediate feedback indicating if the answer provided to the question was right or wrong (Figure 9.10). Future prototypes should include more feedback.

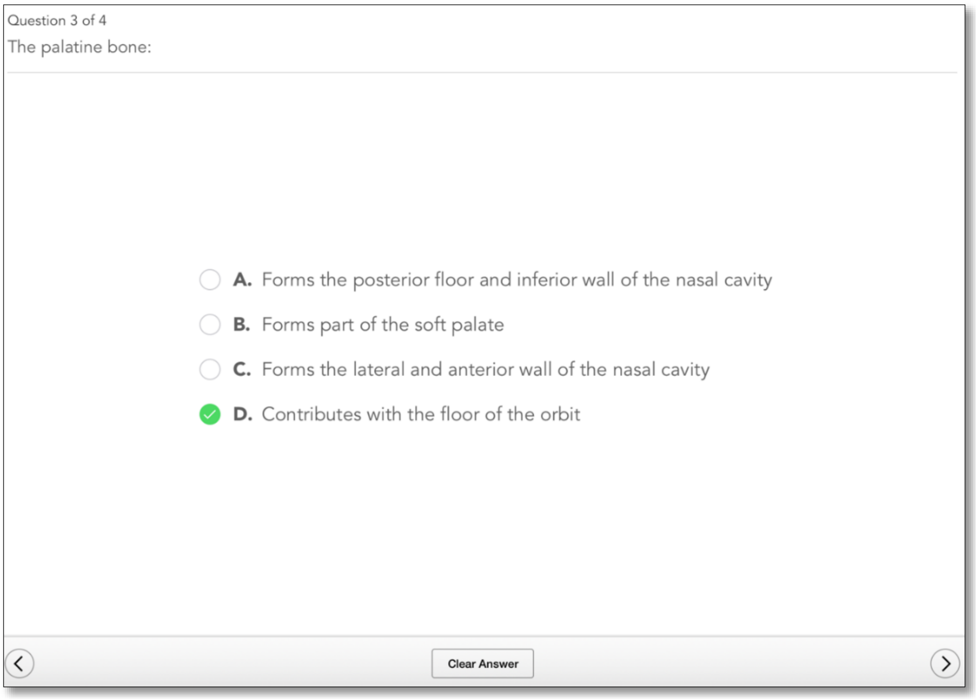


Figure 9.10: Immediate feedback indicating the answer was correct

STEP 8: ASSESSING PERFORMANCE

Self-assessment questions were used to give the student the opportunity to assess their knowledge. These questions provided an opportunity to anchor knowledge and promote reflection. Following the suggestions provided by users of the Tooth morphology iBook, quiz sections were included after each chapter.

STEP 9: ENHANCING RETENTION AND TRANSFER

The last page of each chapter contained external links to further readings and to videos in order to enhance retention. The intention was to help the students' reinforce the learned concepts. This idea stemmed from participants' feedback after testing the Tooth morphology iBook. Adding different sources of information helped to complement students' study. However, if the user decided not to use these links, then the content and navigation of the tool were not compromised (Figure 9.11).

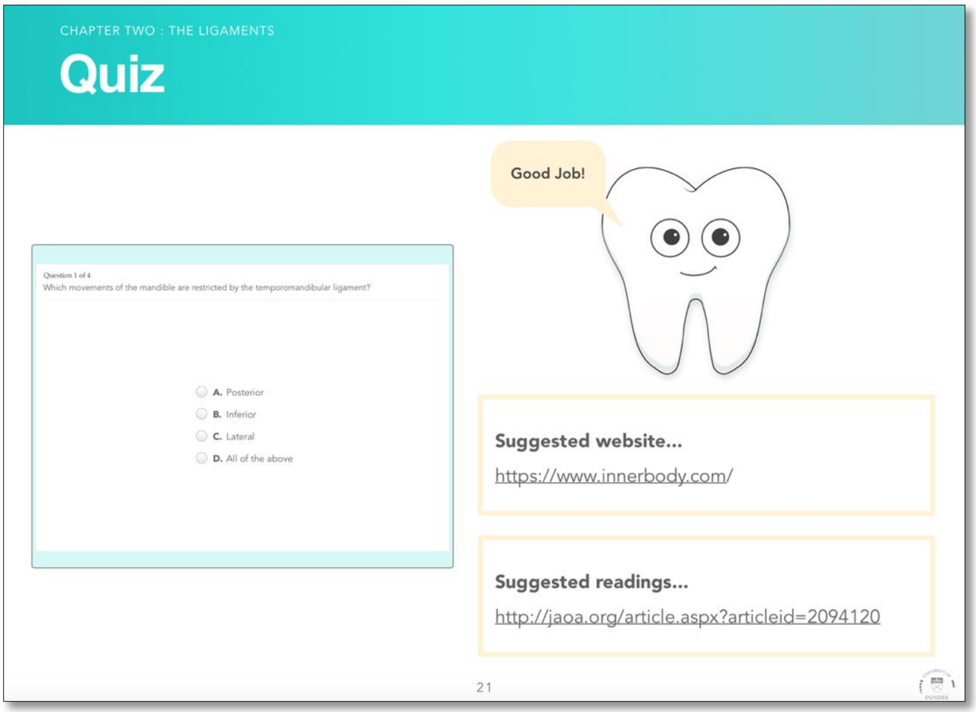


Figure 9.11: External links available at the end of each chapter

9.3 THE PRODUCTION

The Dundee "Anatomy of the TMJ" iBook was created by a multidisciplinary team comprising two medical artists, one clinical photographer and two dentists. The production followed the same three steps used to create the Tooth morphology iBook: the creation of the components, the assembly and testing of each of the elements and the quality assurance process.

9.3.1 CREATION OF THE COMPONENTS

d) 3D MODELS

Two medical artists worked to create the 3D interactive models. One medical artist tried to obtain accurate models producing Collada files smaller than 20 megabytes. However, this was time-consuming because the models were very complex and the resulting files were larger than 20 megabytes, size unsuitable for their use in iBooks. After several attempts, the use of Collada files was replaced by the use of HTML links which directed the user to an online platform named Sketchfab (Paris, France). Sketchfab is a website designed to publish, store and share 3D content ("Sketchfab," 2012). Sketchfab provides a free service of storing and sharing 3D models. To have access, the user needs a personal account and has to upload the desired prototypes. Once uploaded, the models can be shared with registered and non-register users via a link. This allows the iBook user to view and manipulate the 3D models, without the need for a Sketchfab account. On accessing the link, the user can interact with the 3D model: moving it, zooming, activating tags and pausing any movement. A benefit of using HTML linked to Sketchfab is that it allows modification of the models without altering or updating the iBook. Any changes undertaken by the administrator in the original Sketchfab file are updated when the user access the link in the iBook. The drawback of HTML links is that the user needs an Internet connection to achieve proper functioning and display of the models. Requiring an Internet connection compromised the "everywhere" use of the tool. However, it allowed the software to operate and display the models accordingly.

e) Clinical photographs

The clinical photographer used the same technique described in Chapter seven, to capture the clinical photographs required for this iBook.

f) Video

The iBook contained only one animated video. This was produced by the medical artist to exemplify how the articular system works. This animation lasted one minute and thirty seconds and contained text to explain the occurring action. Figure 9.12 shows a screen capture of the video contained in the TMJ iBook.

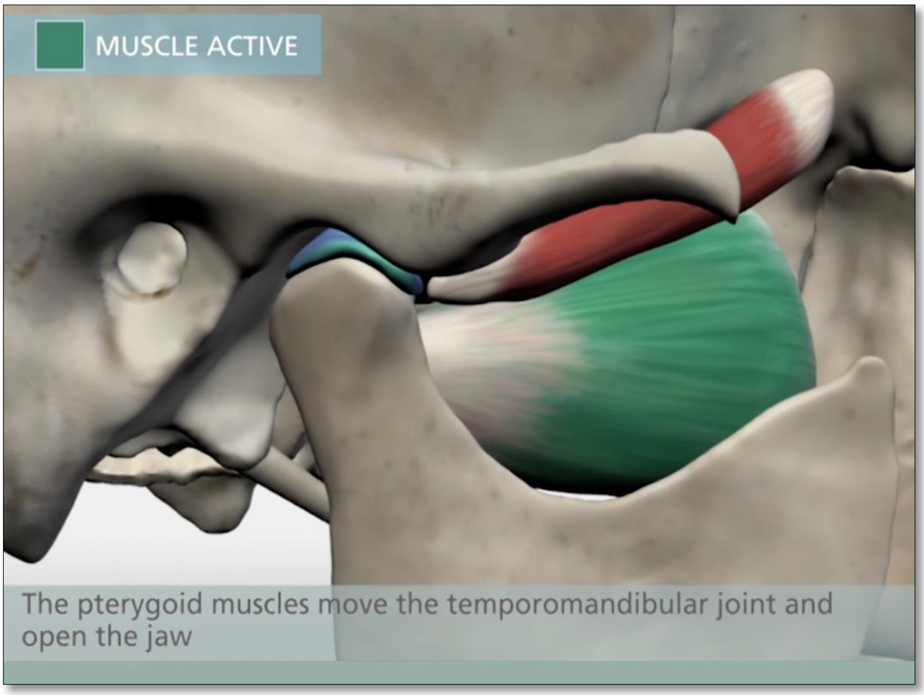


Figure 9.12: Screenshot of the interactive video animation

g) Questions for the quiz section

The researcher designed four questions per chapter to create a quiz section used at the end of each chapter. In total twenty questions addressing key content displayed in the iBook were created. Questions were reviewed by a supervisor to ensure good quality. The quiz section aimed to reinforce the learning process.

h) Text

The researcher wrote the content information describing key aspects of the temporomandibular joint. To ensure accuracy in the factual information references were consulted (Okeson, 2013; Klineberg and Eckert, 2015). To keep the resource as succinct and factual as possible the choice was to use mainly text rather than audio.

9.3.2 ASSEMBLY AND TESTING OF THE COMPONENTS

i) Assembly and design

The design of the TMJ iBook was similar to the one described for the Tooth Morphology iBook. The researcher and the medical artist created a template to determine the look of the resource. The design of each page was simple and redundant elements were eliminated. Symmetry and efficient use of space provided the desired appearance.

The font and colours selected were different from the first iBook. As shown in the Figure 9.13 the choice was to use a white background and dark grey fonts. For titles and highlighted text, teal background, and white fonts were selected to provide a modern aspect. Dark fonts and light backgrounds are ideal for reading (Humar et al., 2008).

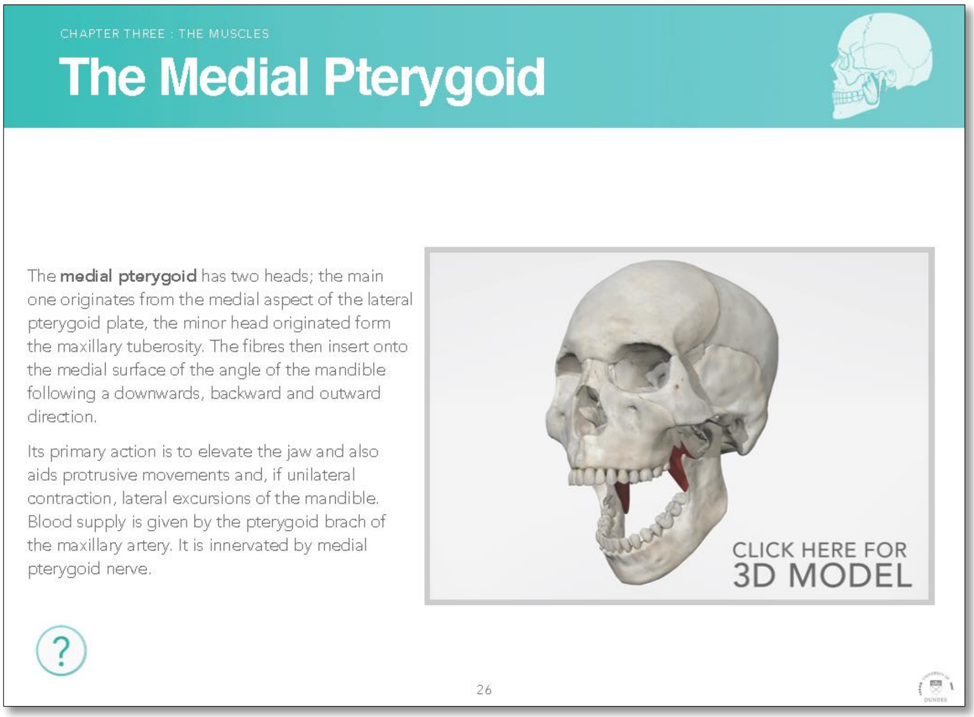


Figure 9.13: Example of the text and font selected for the TMJ iBook

j) Testing

The testing process was similar to the one detailed in Chapter seven.

k) Quality assurance

As explained in Chapter seven, the multidisciplinary team involved in the creation and development of the resource reviewed the iBook until all the features and functionality met the initial specifications.

9.4 THE FINAL RESULT

The finished iBook had thirty-eight pages, twenty 3D models, four interactive photo galleries, five review-quiz sections and one animated video. Appendix eight shows a PDF document with a complete copy of the iBook.

9.5 THE 2D iBOOK VERSION

The construction of the 2D version was straightforward. iBooks Author allows the user to duplicate a document easily (Figure 9.13). Once the researcher duplicated the iBook, the 3D models were replaced by standardised stills of the models. Examples of some of the pages of this new iBook are shown Figures 9.14 and 9.15. Overall the iBooks were almost identical, only the 3D and 2D components were different. These two instruments were used to explore if the use of 3D interactive models has an impact on the learning process (further details in Chapter ten). The complete version of the 2D iBook is shown in Appendix nine.

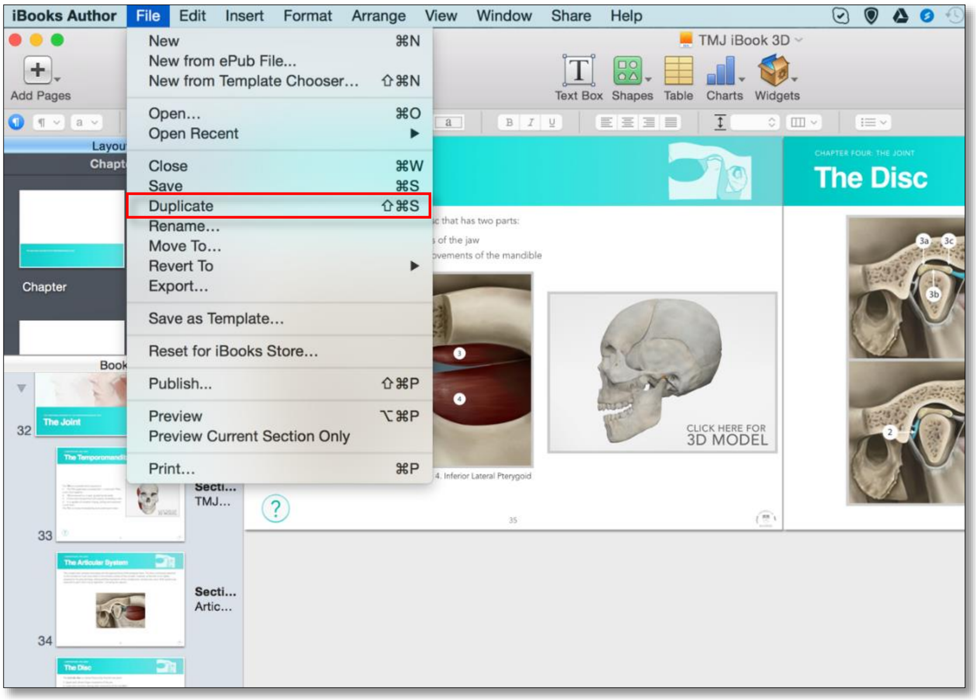


Figure 9.14: Duplication process of the 3D iBook

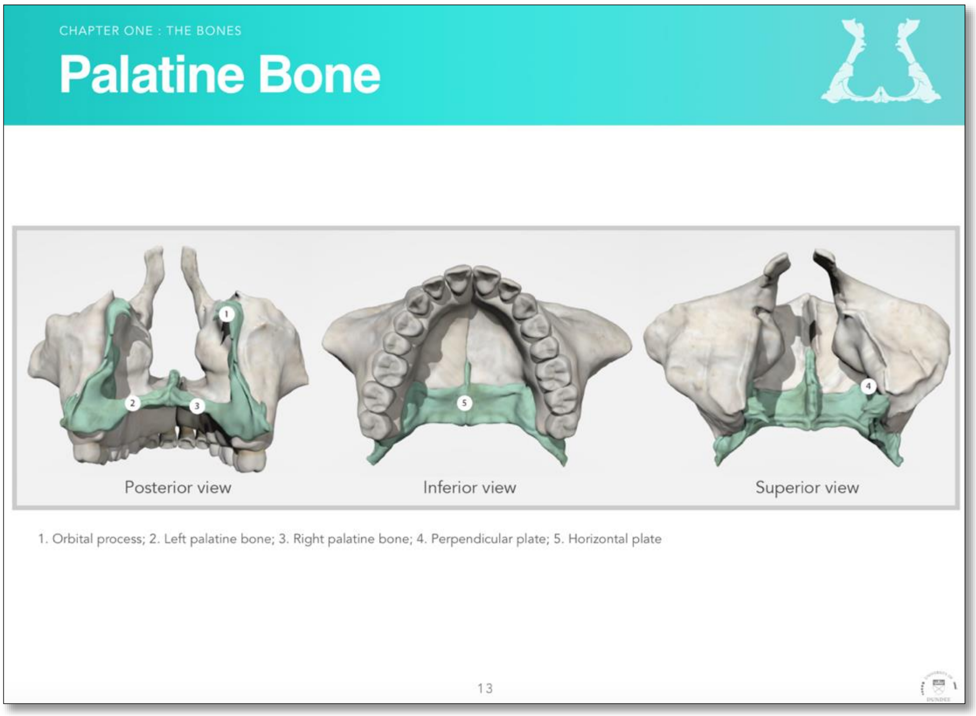


Figure 9.15: Example 1 of the images used in the 2D version iBook

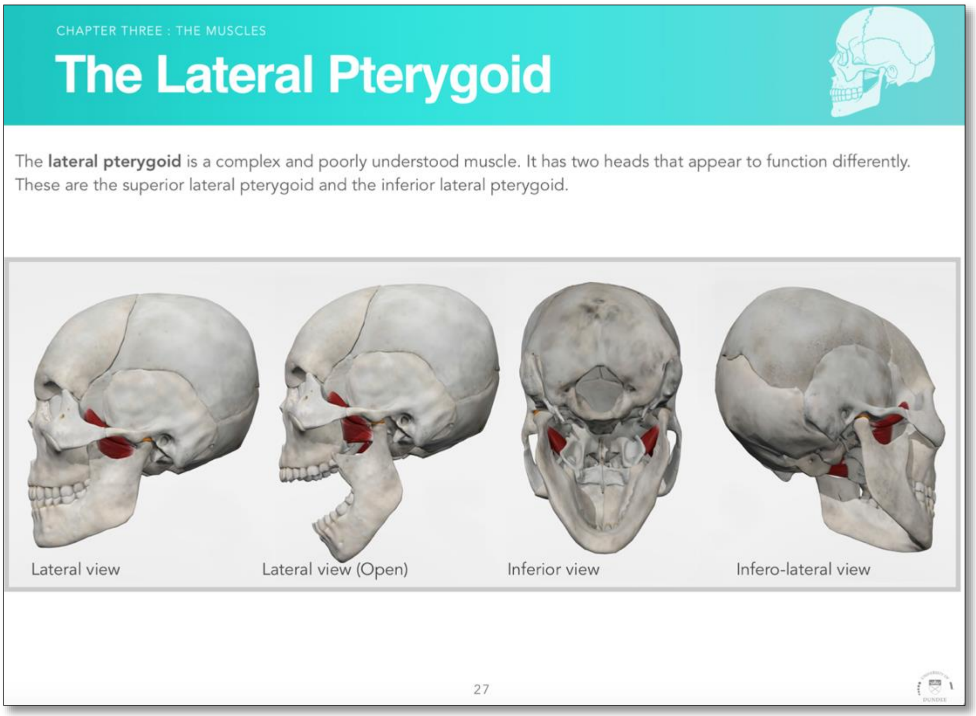


Figure 9.16: Example 2 of the images used in the 2D version iBook

10 THE IMPACT OF 3D VERSUS 2D USING iBOOKS

10.1 INTRODUCTION

This chapter starts with a review of the literature about the use of 3D models for learning. Then, it describes the research method used to assess the impact of 3D models, followed by the description of the results obtained. Findings of the experience are discussed at the end of the chapter.

10.2 BACKGROUND

3D animations and simulations have become popular. There are numerous accounts of the use of 3D resources in the literature, especially in the field of anatomy (Mitov et al., 2010; Wright and Hendricson, 2010; Codd and Choudhury, 2011; Petersson et al., 2009; Battulga et al., 2012; Nguyen and Wilson, 2009; Henn et al., 2002; Nicholson et al., 2006; Salajan et al., 2009; Brown et al., 2012). These resources are reusable, and some believe that in the long term they are less expensive than traditional teaching methods (Hisley et al., 2008; Petersson et al., 2009; Jones, 1997). In addition, the use of 3D is reported to have fewer ethical issues than cadaveric dissections for anatomical studies (Nguyen and Wilson, 2009). Despite the significant amount of 3D tools created for education, chapter three of this study demonstrated that several areas of dental education have the need for 3D learning resources, being the functional anatomy of the temporomandibular joint (TMJ) the one believed to have the greatest need.

In medical and dental education the users' perceptions have been mainly measured using questionnaires (Hu et al., 2010; Salajan et al., 2009; Vuchkova et al., 2011;

Prinz et al., 2005; Wright and Hendricson, 2010; Mitov et al., 2010; Hariri et al., 2004; Keller and Cernerud, 2002). Nor is the literature completely clear about the benefits of 3D digital technologies for education, as very few studies have explored their educational impact. Most publications in health science education addressing digital 3D focus on the development of new resources (Rubin et al., 1998; Warrick and Funnell, 1998; Henn et al., 2002; Brenton et al., 2004, 2007; Grimstead et al., 2007; Nowinski et al., 2009; Nguyen and Wilson, 2009; de Ribaupierre and Wilson, 2012).

In dentistry, the situation is similar as most papers are descriptive rather than experimental (Spallek et al., 2000; Suman et al., 2010; Dias et al., 2011; Wang et al., 2012; Kim et al., 2009; Ammann et al., 2010). One randomised control trial conducted by Qi et al. (2013) compared results of a post-test of students who used a computer web page about dental implantology. The study compared the results of three groups; one using 2D models, one using 3D without guidance, and one using 3D with guidance and restrictions on how the user could manipulate the model. Students who used the guided 3D web pages achieved higher scores on a post-intervention test. The assessment measured knowledge using a written test composed of forty questions. Unfortunately, the authors did not provide further details about the evaluation tool. In addition, no description of a pre-test baseline test was given. Therefore, it is not clear if the benefits were a consequence of the 3D or due to a starting difference between the groups.

Thus, it is of great interest to see if dental students' knowledge and ability to identify structures related with the TMJ improves after using an e-learning resource containing 3D models.

10.3 AIMS

This study aimed to assess the impact of 3D model in learning. For this purpose, the researcher used two iBooks about the anatomy of the temporomandibular joint and the masticatory system. One contained 3D interactive models and the other one had 2D images representing the same structures. Also, this study explores the perceptions of users of the e-learning resource.

10.4 METHODOLOGY

10.4.1 METHOD

A mixed method was used divided into two stages. The first stage was planned as a pre-test/intervention/post-test and a perception questionnaire. These methods had been extensively employed in other studies in the field of dental education, medical education and computer science (Peroz et al., 2009; Vichitvejpaisal et al., 2001; Hopkins et al., 2011; Qayumi et al., 2004; Mayfield et al., 2013; Devitt and Palmer, 1999; Plasschaert et al., 1997; Al-Riyami et al., 2010). The researcher planned the intervention as a self-learning session where the participants had access to an e-learning resource.

The second stage used focus groups. The sessions were planned following Krueger and Casey (2002) recommendations using a similar structure and approach as previous focus groups described in this dissertation.

10.4.2 ETHICAL CONSIDERATIONS

This study received clearance from the University of Dundee Ethical Committee (UREC: 15114 – Appendix 11). The researcher had no prior relationship with the participants. Subjects knew their involvement was voluntary (WMA, 2008) and that they had the right to withdraw at any time. All participants were asked to give written informed consent. The researcher collected all data and stored it securely.

To avoid any positive or adverse effect on the use of either one of the iBooks (3D or 2D), students had access to the 3D or 2D iBook after the intervention if they wished.

10.5 STAGE 1: THE EXPERIMENTAL INTERVENTION

10.5.1 SAMPLE AND RECRUITMENT

The researcher wanted to compare novice students with more advanced students. First-year and third-year dental students from Dundee Dental School were the target population following a convenience sampling technique. First-year students fitted in the novice category, while third years students were chosen to represent the advanced group. Both groups of students had time in their academic schedules to fit the intervention, so it was convenient to use these academic cohorts. It was important that participants had completed their formal instruction on the TMJ and masticatory muscles in order to be familiar with terms and concepts. Also, it was mandatory that the students did not have any previous contact with the assessment tool and the TMJ iBook.

For recruitment every student in first and third-year received an email invitation with details of the study (similar to Appendix 2) explaining the aims, importance and structure of the study. Also, the researcher presented the study to first-year and third-year students during one of their lectures.

10.5.2 INTERVENTION SESSION

The pre-test/post- test intervention plan can be seen in Figure 10.1.

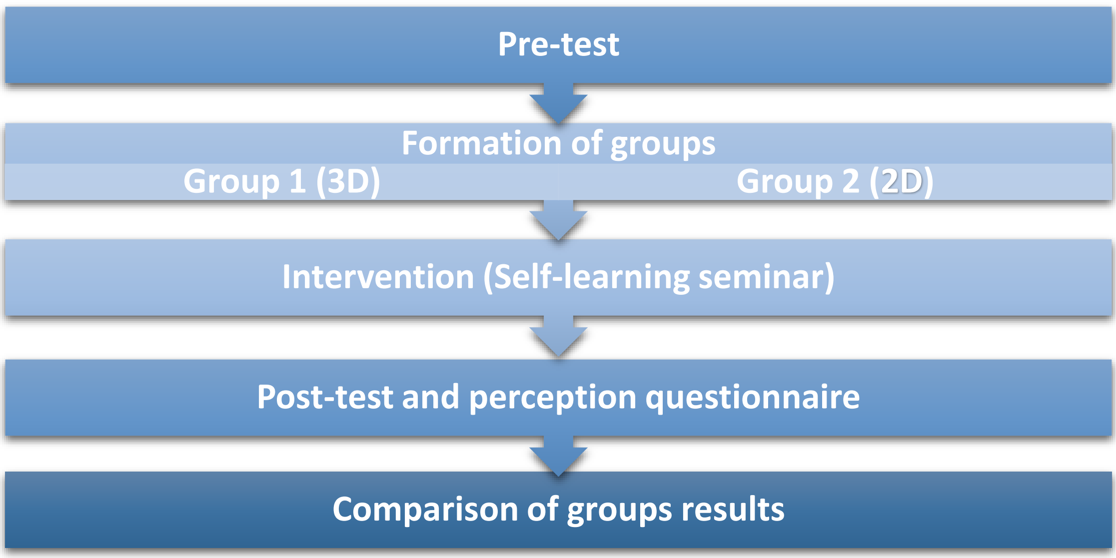


Figure 10.1: Intervention planning

The exact number of volunteers was unknown until the day of the intervention; therefore, random group allocation of participants was not possible. However, the treatment of the first participant who attended the session was randomised followed by alternate allocation of the rest of the participants.

The first-year class had a total number of fifty-nine students divided into six groups. For the intervention each group was invited at different times during a morning slot. The intervention was arranged differently for the third-year students (n=61). Considering their academic commitments, the researcher arranged multiple sessions depending on their availability. Data collection for third-year students took four weeks as participants showed up in small groups or individually.

The researcher prepared an intervention pack for each student. The pack included a consent form, information sheet, a pre-test, a post-test, a questionnaire and an iPad with the 2D or 3D version of the TMJ iBook. The researcher went through the process to calculate an approximate execution time for the intervention. The estimated time was of fifty minutes (Figure 10.2). However, it was not an issue if a student needed more or less time to complete the process.

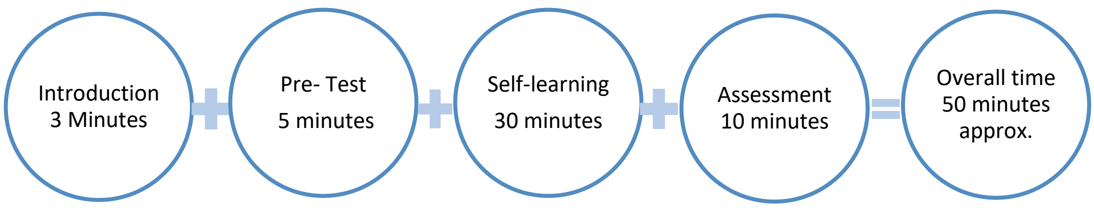


Figure 10.2: Estimated timings of the intervention

10.5.3 THE ASSESSMENT TOOL

An assessment tool was designed to compare the impact of the 3D and the 2D learning resources. The developmental rationale determined that the test needed to assess 3D thinking and spatial ability of students. Therefore, questions required images of CT scans and MRIs of the joint. To obtain suitable visual material, the researcher contacted Dr. Surdarshan, Consultant Radiologist at Ninewells Hospital, Dundee. After the aims of the study had been explained, the consultant agreed to share the requested visuals of the TMJ. Several image packages were reviewed, using OsiriX Lite software (Pixmeo SALR Geneva, Switzerland) in order to select the ones representing most normal TMJs. Identity of the patients was protected and removed from the images. No ethical issues were perceived when using this material, as patients attending the radiology department at Ninewells Hospital consented the use of their images for educational purposes.

Eleven questions were created, which resulted in a maximum score of nineteen points as some questions had more than one component. The assessment contained multiple choice, "True" and "False" and short answers questions. An example is shown in Figure 10.3, while Appendix 10 contains the complete evaluation material. Questions were carefully designed by the researcher and validated by one of the supervisors of this project.

1. In the horizontal section below the patient shown in the CT scan has his mouth closed. If simultaneous contraction of the inferior head of the lateral pterygoid occurs and a second the same image is taken in the same position, would you see?
    A) A bigger section of the left condyle
    B) A smaller section of the left condyle
    C) The same proportion of the left condyle

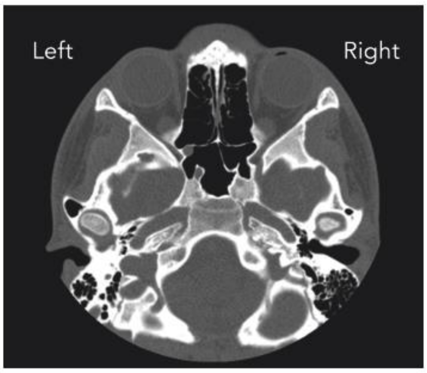


Figure 10.3: Question one of the assessment tool

10.5.4 PERCEPTION QUESTIONNAIRE

The researcher designed a questionnaire containing fourteen questions, twelve using a five-point Likert scale, and two using multiple choice format. This questionnaire aimed to assess the users' perception in regards to the TMJ iBook.

Ten questions addressed features about the iBook, two asked how participants perceived the assessment tool, one asked them about the time used exploring the iBook and the last question asked them about their gender. Figure 10.4 shows an extract of the questionnaire while the complete instrument can be found in Appendix 12.

Anatomy of the TMJ and the masticatory system

Please choose the best answer for each of the following statement

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
The Anatomy of the TMJ and the masticatory system iBook is easy to use	○	○	○	○	○
The content is well designed	○	○	○	○	○
The use of the Anatomy of the TMJ and the masticatory system iBook has facilitated my studies	○	○	○	○	○
This teaching method motivates me to learn	○	○	○	○	○
The volume of information is appropriate	○	○	○	○	○
I am satisfied with the 2D images	○	○	○	○	○
The 2D content is of high quality	○	○	○	○	○
I have enjoyed learning Anatomy of the TMJ and the masticatory system with the 2D interactive iBook	○	○	○	○	○
Learning Anatomy of the TMJ and the masticatory system seems easier with a 2D iBook than with textbook	○	○	○	○	○

Figure 10.4: Student's perception questionnaire

10.5.5 EXPERIMENTAL INTERVENTION RESULTS

Twenty-seven out of the fifty-nine first-year students participated in this study (46%). Fourteen received the 3D version iBook, and thirteen had access to the 2D version one. Twenty-four participants were females; two were males, and one participant did not answer the question.

Thirty-three out of the sixty-one (54%) third-year students took part in the study. Eighteen were females, thirteen males and two participants did not declare their gender. Seventeen received the 3D iBook and sixteen the 2D version.

The mean scores for the first-year and third-year students pre-test / and post-test are shown Table 10.1 and 10.2 respectively.

Table 10.1: Results of the pre-test/post-test first-year students

3D group			2D group		
Participant	**Pre-test**	**Post-test**	**Participant**	**Pre-test**	**Post-test**
1	5	8	**1**	8	6
2	10	12	**2**	6	7
3	4	11	**3**	7	8
4	13	11	**4**	5	9
5	14	15	**5**	11	12
6	10	9	**6**	11	10
7	13	15	**7**	9	8
8	6	9	**8**	15	15
9	6	7	**9**	10	9
10	9	12	**10**	11	14
11	6	12	**11**	14	15
12	6	11	**12**	9	8
13	11	15	**13**	4	5
14	5	10			
Total	118	157	**Total**	120	126
Mean	8.4	11.2	**Mean**	9.2	9.7
% of improvement using 3D = 33%			**% of improvement using 2D = 5%**		

Table 10.2: Results of the pre-test/post-test third-year students

3D group			2D group		
Participant	**Pre-test**	**Post-test**	**Participant**	**Pre-test**	**Post-test**
1	8	6	**1**	9	10
2	12	12	**2**	13	15
3	11	11	**3**	2	2
4	5	8	**4**	2	15
5	5	9	**5**	3	10
6	6	9	**6**	3	10
7	1	3	**7**	12	13
8	6	9	**8**	8	8
9	7	10	**9**	7	8
10	8	9	**10**	10	7
11	11	11	**11**	10	10
12	7	15	**12**	10	10
13	7	10	**13**	6	10
14	9	10	**14**	7	9
15	8	7	**15**	5	4
16	10	12	**16**	7	8
17	13	10			
Total	134	161	**Total**	114	149
Mean	7.9	9.5	**Mean**	7.1	9.3
% of improvement using 3D = 17%			**% of improvement using 2D = 23%**		

10.5.6 INTERVENTION STATISTICAL ANALYSIS

Quantitative data was analysed using SPSS statistical analysis software and Microsoft Excel.

A two by two-way factorial ANOVA test was used to determine any differences between the 3D and the 2D groups. This method was selected as data was expected to be normally distributed and heterogenic. Heterogeneity was tested using Leven’s test. Results of this test supported the assumption of heterogeneity.

Normality was assumed as the sample of each class year was more than or close to thirty participants. A separate analysis was carried out for each year cohort.

The results of the analysis for the first-year group showed a significant interaction between pre-test/post-test and a significant interaction between the 3D and 2D learning method. These results are shown in Figure 10.5. The slope of the curve between the pre-test and the post-test was significantly different between the 3D and 2D groups demonstrating a significant interaction of the treatment applied.

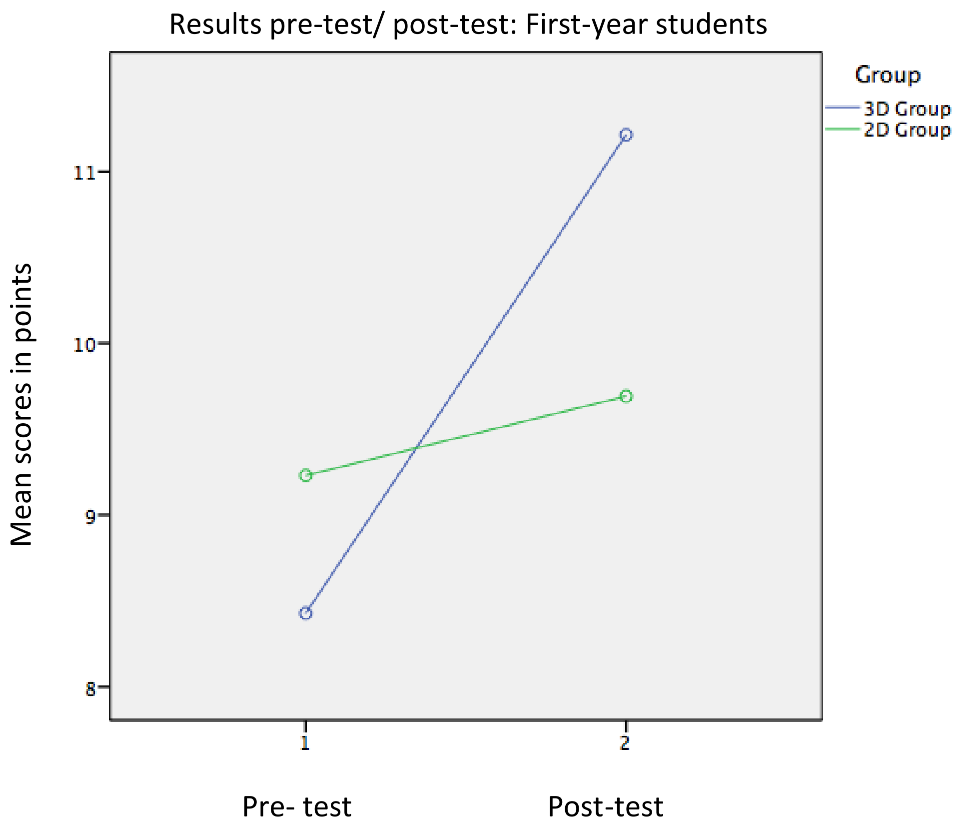


Figure 10.5: Interaction of the performance from the first-year student's cohort

The analysis of the third-years revealed a significant difference between pre-test and post-test but no interaction between the two curves of the 3D and 2D treatments (Figure 10.6). These results indicate that both versions of the iBook had a positive effect on the post-test results, but no statistical difference was observed between the 3D and 2D tools.

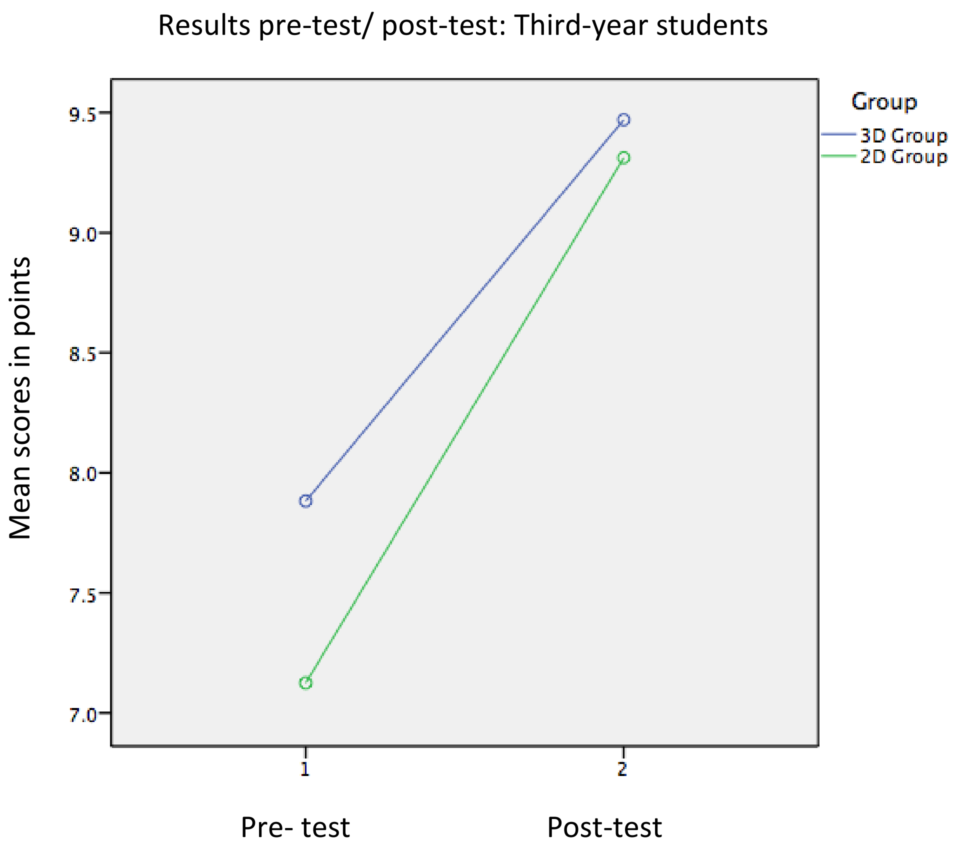


Figure 10.6: Interaction of the performance from the third-year student's cohort

10.5.7 RESULTS FROM THE PERCEPTION QUESTIONNAIRE

All participants completed the prepared questionnaire. Data was arranged and organised using Microsoft Excel. Data was analysed using a Wilcox U rank test. No statistical difference was found between the 3D and the 2D groups for both years of study. Table 10.3 and Table 10.4 represents the responses of the participants in percentages. Overall, students liked the iBooks and the interactive elements. They were highly positve towards the design, ease of use and content quality. Also, the majority of participants indicated that the resource should be available for all students in the school.

Table 10.3: Questionnaire responses first-year students

Statement	Group	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
The Anatomy of the TMJ and the masticatory system iBook is easy to use	2D	12(92%)	1(8%)	0(0%)	0(0%)	0(0%)
	3D	8(62%)	6(46%)	0(0%)	0(0%)	0(0%)
The content is well designed	2D	10(77%)	3(23%)	0(0%)	0(0%)	0(0%)
	3D	9(69%)	5(38%)	0(0%)	0(0%)	0(0%)
The use of the Anatomy of the TMJ and the masticatory system iBook has facilitated my studies	2D	6(46%)	6(46%)	1(8%)	0(0%)	0(0%)
	3D	9(69%)	5(38%)	0(0%)	0(0%)	0(0%)
This teaching method motivates me to learn	2D	5(38%)	7(54%)	1(8%)	0(0%)	0(0%)
	3D	6(46%)	5(38%)	3(23%)	0(0%)	0(0%)
The volume of information is appropriate	2D	6(46%)	6(46%)	1(8%)	0(0%)	0(0%)
	3D	8(62%)	4(31%)	2(15%)	0(0%)	0(0%)
I am satisfied with the models	2D	5(38%)	5(38%)	2(15%)	1(8%)	0(0%)
	3D	10(77%)	4(31%)	0(0%)	0(0%)	0(0%)
The content is of high quality	2D	8(62%)	4(31%)	0(0%)	0(0%)	0(0%)
	3D	8(62%)	5(38%)	1(8%)	0(0%)	0(0%)
I have enjoyed learning Anatomy of the TMJ and the masticatory system with the interactive iBook	2D	6(46%)	6(46%)	1(8%)	0(0%)	0(0%)
	3D	10(77%)	4(31%)	0(0%)	0(0%)	0(0%)
Learning Anatomy of the TMJ and the masticatory system seems easier with an iBook than with textbook	2D	7(54%)	5(38%)	1(8%)	0(0%)	0(0%)
	3D	9(69%)	5(38%)	0(0%)	0(0%)	0(0%)
The Anatomy of the TMJ and the masticatory system iBook should be made available on blackboard for all dental students	2D	11(85%)	2(15%)	0(0%)	0(0%)	0(0%)
	3D	12(86%)	2(14%)	0(0%)	0(0%)	0(0%)
I feel the test measured my knowledge	2D	8(62%)	3(23%)	2(15%)	0(0%)	0(0%)
	3D	5(38%)	1(8%)	6(46%)	1(8%)	0(0%)
My responses were influenced heavily by my previous knowledge on the subject	2D	3(23%)	6(46%)	4(31%)	0(0%)	0(0%)
	3D	2(15%)	8(62%)	2(15%)	1(8%)	0(0%)

Table 10.4: Questionnaire responses of third-year students

Statement	Group	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
The Anatomy of the TMJ and the masticatory system iBook is easy to use	2D	14(88%)	1(6%)	1(6%)	0(0%)	0(0%)
	3D	14(82%)	3(18%)	0(0%)	0(0%)	0(0%)
The content is well designed	2D	13(81%)	3(19%)	0(0%)	0(0%)	0(0%)
	3D	15(88%)	2(12%)	0(0%)	0(0%)	0(0%)
The use of the Anatomy of the TMJ and the masticatory system iBook has facilitated my studies	2D	11(69%)	5(31%)	0(0%)	0(0%)	0(0%)
	3D	15(88%)	2(12%)	0(0%)	0(0%)	0(0%)
This teaching method motivates me to learn	2D	10(63%)	4(25%)	2(13%)	0(0%)	0(0%)
	3D	13(76%)	3(18%)	1(6%)	0(0%)	0(0%)
The volume of information is appropriate	2D	9(56%)	6(38%)	1(6%)	0(0%)	0(0%)
	3D	11(65%)	5(29%)	1(6%)	0(0%)	0(0%)
I am satisfied with the models	2D	12(75%)	2(13%)	1(6%)	1(6%)	0(0%)
	3D	14(82%)	2(12%)	1(6%)	0(0%)	0(0%)
The content is of high quality	2D	13(81%)	3(19%)	0(0%)	0(0%)	0(0%)
	3D	9(53%)	7(41%)	1(6%)	0(0%)	0(0%)
I have enjoyed learning Anatomy of the TMJ and the masticatory system with the interactive iBook	2D	11(69%)	4(25%)	1(6%)	0(0%)	0(0%)
	3D	14(82%)	3(18%)	0(0%)	0(0%)	0(0%)
Learning Anatomy of the TMJ and the masticatory system seems easier with an iBook than with textbook	2D	11(69%)	5(31%)	0(0%)	0(0%)	0(0%)
	3D	14(82%)	3(18%)	0(0%)	0(0%)	0(0%)
The Anatomy of the TMJ and the masticatory system iBook should be made available on blackboard for all dental students	2D	13(81%)	3(19%)	0(0%)	0(0%)	0(0%)
	3D	16(94%)	1(6%)	0(0%)	0(0%)	0(0%)
I feel the test measured my knowledge	2D	6(38%)	7(44%)	2(13%)	0(0%)	0(0%)
	3D	5(29%)	7(41%)	3(18%)	1(6%)	0(0%)
My responses were influenced heavily by my previous knowledge on the subject	2D	4(25%)	5(31%)	4(25%)	2(13%)	0(0%)
	3D	4(24%)	5(29%)	5(29%)	2(12%)	0(0%)

10.6 STAGE 2: THE FOCUS GROUPS

10.6.1 THE SAMPLE AND THE RECRUITMENT PROCESS

The researcher recruited participants for the focus group during the experimental intervention. A form asking about the willingness to participate was included in the intervention pack. Those particpants who agreed to take part in the focus group were contacted by email. The email included an information sheet with details of the session and the data collection process.

10.6.2 DATA COLLECTION

The questions used during the focus group emerged from the results of stage one of this chapter. The sessions were arranged to suit the volunteer's availability. The students received an information sheet explaining the data collection process before the session. The researcher collected written, and verbal consent before commencing the focus groups. Data was collected using a MacOS laptop. During the recording, participants were not addressed by their names to protect their identity.

10.6.3 FOCUS GROUP RESULT

The researcher conducted three focus group sessions: one with first-year students and two with third-year individuals. In total eleven participants volunteered for the experience. The first meeting was conducted immediately after the intervention; six females from first-year participated. The researcher scheduled the two sessions with third-years a few days after the experimental session. In total three males and two females took part in the third-year focus groups.

Qualitative data was analysed following a framework coding analysis similar to the one explained in Chapter eight. To identify themes and codes in the data, the researcher sought repetition, similarities and difference among the emerging concepts. Looking for repetition is an easy way to identify themes in the data (Ryan and Bernard, 2003). The data was organised using a “cutting and sorting” technique using NVIVO-10 software package. The reseacher divided the data in five main groups. Each group was then subdivided in themes. Tables 10.5 to 10.9 show the identified categories and themes that emerged from the data.

Table 10.5 contains reasons why people liked the iBooks. Twenty-eight statements indicating felt into this category. The most common reasons were because the information was well structured, brief, explanatory, and that it had several media and interactive features. Participants also liked the quiz section at the end of each chapter and the external links for further readings. Users indicated that the iBooks were easy to use because of the layout and how the content was displayed. The iBook was valued because of being an e-mobile resource. Three comments suggested that students felt motivated to use the iBooks for learning. Motivation was driven by the interactive features of the resource.

Table 10.5: Reasons why the participants liked the iBooks

Themes	Number of quotes	Most representative quotes
Use of media and widgets	5	• It helps you to remember easier… cos you can remember the images, instead of just line text, I think it makes it more easy • It gives you something to do, it makes much more interactive and this is much easier cos it is broken down.
Navigation	1	• This one is a just left-hand scroll, so you can read it as a book.
Layout of the information	5	• Is like having the picture over there and then just the information you need, it's easy to read not like bulky paragraphs • It is sized down makes it more manageable
Outlook Design	3	• I think it was really appealing, it was gender neutral, and the colours were not too bright and they weren't dull, so… • I thought it was nice, nicely done. Like any Apple presentation it looked slick.
iPad format	4	• I like to sit in my bed while studying rather than sitting in my desk flipping books haha. • Researcher: you mentioned before you are inclined to use iPads… but is this platform appealing for students in general? Participant: you mean the iPad format? Researcher: yes… Participant: it would appeal to a lot of students, but having something compatible with android tablet or android phone would be great
Motivation	3	• It takes away that boring element (people laugh), cos if you just have a textbook, with lines and lines… • Participant 1: I think definitely the motivation part cos people would be more motivated to use something interactive than a piece of paper Participant 2: absolutely! Certainly more fun! Hehe
Using the iBook was easy	2	• It was quite easy to read. • Yes, it was easy to read. Quite simple, not hard to understand.

There were twenty-nine statements related to the benefits of 3D. The researcher divided this category into seven themes (Table 10.6). Participants indicated that the 3D models ease learning, as they caught their attention and helped them to stay focused on the 3D models for longer. Interactivity was one of the strongest advantages reported by users, as they could manipulate the 3D models as they wanted. The 3D models helped student visualise the structures from different angles and positions, benefiting their understanding, spatial ability and learning.

From a clinical perspective participants indicated that the 3D models were beneficial as they were closer to reality than 2D textbook images, and enhanced their confidence for practice.

Table 10.6: Perceived benefits of 3D

Themes	Number of quotes	Most representative quotes
Anchor learning	3	• Cos you've just got a prosection and so the 3D models allow you to work out where everything is and helps teaching
Catch student attention	4	• You can spend lot of more time with the 3D model interested, rather than looking at 2D picture and trying to recreate that picture in your mind when you look away from the iPad and with the 3D image you can be constantly interpreting things I guess • For me I guess the biggest dealmaker is the 3D
Easier to learn	2	• I think is far easier to learn from the 3D model as to the 2D picture
Interaction	5	• I see big advantages on the 3D, as been able to rotate and in fact being able to zoom in it is maybe more useful. • I think I definitely prefer the 3D for looking at the muscles in conjunction to the text and the rest of the joint and being able to move the head around being able to see it from every view I want rather than just the snippet of the picture that are there
Orientation	4	• I think is easier to orientate yourself in some things hum on the 3D version. • You can orientate structures better in your mind so when you say I have spotted that in a cadaver and you are trying to figure out which layer it is you can say which layer have been off so know on which layer you are so the depth perception you get is another advantage I see.
Visualise	8	• It is good to see bones from a different angle (people agrees), because sometime with the skull are things hiding and can't see • Over the 2D I rather the 3D obviously, cos with it you can visualise it and then you have it in your head and you know where it is and think like that
Clinical relevance	3	• Is more relevant to thinks encounter clinically because if you see a structure let's say in a radiograph or even in a dissection it is never going to be exactly the same orientation as it is in a textbook or if you might remove more muscles or fascia for example and as with the 3D model you get closer to the angulation and to what you actually see in real life. • I would definitely be more confident having used the 3D instead of the 2D

In regards to the results of the pre-test and post-test, the researcher asked participants which group (2D or 3D) they thought did better. Data demonstrated that most participants, from first and third-year, believed that the 3D group did better in the post-test. Only two students from the complete sample were unsure about the results (Table 10.7)

Table 10.7: About the results of the pre-test and post-test

Themes	Number of quotes	Quote from participants
Results of the test	7	• With the 3D one I think that the results were better, cos I was able to see the 3D version and see those angles and then see them in the picture, so I think I had a better idea, I think did better. • It felt like having done the test with the 2D book was OK but knowing there was a 3D one, I think I would've been done better (two participants agree) • I don't know to be honest! Hahaha it could've gone either way so… haha. Right… I think that…

The researcher discussed the results of the intervention with the third-year students. Before disclosing the results, most participants believed that first-year did better in both tests. One student suggested that the third-years did better in the pre-test but worse in the post-test; while another participant was confident that the third-years did better in the post-test as the tool was a good reminder material. After disclosing the results, one participant indicated that maybe first-year students do not have that capacity to "generate a 3D model in their minds", thus the use of the iPad containing the 3D model was helpful. Other third-year participants indicated that maybe first-year students paid more attention to names of structures than third-year students (Table 10.8).

Table 10.8: Third-year students' thoughts about the results of the two groups

Themes	Number of quotes	Most representative quotes
Before knowing the results	7	• Hum… I think that the knowledge that they have, the first years is way more than the one we have so they remember more than what was taught in the iPad. Hum…They probably have a better awareness of 3D space because they just dissected cadavers and stuff… hum. • I think maybe they did better in the first test but we did better in the second one…cos they might have things fresher than us… • Yeah…but the first years just covered the topic… (Thinking) so I guess them…
After knowing the results	5	• But maybe the 3D iBook helped the first years to consolidate their dissection but for us has been so long since we did that so maybe they made no difference. • So for them is much more helpful to have a 3D model cos that gives them that vital information to rotate and to understand a CT scan. Whereas we know how the real 3D model is and it does not really matter if it is in 2D or 3D • At this point we have created a 3D model in our head from the 2D images we've seen along our study. So is like we are looking at the 2D but almost doing the 3D model in our head already. Whereas, the first years aren't at that stage yet so getting the actual 3D model was much more helpful and it comes from not visualising it in 3D already.

There were seventeen suggestions for improvements grouped into five themes (Table 10.9). Among the suggestions were the addition of further questions in the quiz section and more videos. One student mentioned the importance of having a compatible version for Android and Microsoft operating systems. When looking at suggestions for improvement of the 3D model, two participants indicated that ideally the model should not be pixelated when zooming. One participant was very direct and suggested an entirely different outlook where a virtual reality head should replace the iBook. However, this idea was not supported by other participants of the focus groups as they thought that would make the material too comprehensive.

Table 10.9: Suggestions for improvements of the iBooks

Themes	Number of quotes	Most representative quotes
Improvements for the 3D models	4	• Hum… quality can be better when you zoom in it becomes pixelated • There are a lot of 3D models and they all offer something different, but in reality they are quite the same, bones of skull with different highlighted and them you have the questions but it is all separated… and yes you can choose to do this bit or that bit if you want, but for me really… you really should have one head model and the model be the book and then choose if you want floating bullets points or floating answers…so the model is the book I suppose that instead of doing a book with the model…
Addition of other features	3	• Even if there is an audio clip with the diagram, like if you click on something, if you would like more information, there could be and audio with it that explains the function of what you are looking at • Links for further readings… if there were more links broken into more further reading… in case you wanted to dig deeper… saying ok this is the core, but if you wanted to go deeper, you had the suggested reading so you could go and find it yourself.
More questions	5	• I've would like more questions • Because if you have more questions it helps you revise what you have learned from the previous slides so… it is like a summary, so I think it would be good if you have like more questions. • Each chapter covered a lot so you could do way more questions
Use of other platform	1	• It would appeal to a lot of students, but having something compatible with android tablet or android phone, I don't know what is best… everyone has a laptop
Further topics	4	• Hum… it would be great if we could have an app or an iBook that covered the whole head and neck or at least all the anatomy we cover. It would be good if it could have extra features like local anaesthetic that it shows where exactly the needle should be placed in 3D or for example oral surgery where it shows you exactly how to cut a flap or exactly where you place an elevator or force or… maybe it could be used for other subjects, maybe for perio you could see exactly who you could angle the probes or currents in 3D • Yeah that would be amazing! Yes... because right know we have different lectures from different lecturers, different formats, different files, different sources... it all becomes a mess in the computer… everyone uses a computer anyhow… so having all in one book… would be great

10.7 DISCUSSION

Several papers have examined the use of 3D for dental education (Hu et al., 2009; Maggio et al., 2012; Qi et al., 2013; Vuchkova et al., 2011; Kikuchi et al., 2013; Papadopoulos et al., 2013). However, there is still a need to quantify their educational impact (Brenton et al., 2007).

The results of this intervention suggest that 3D models have the potential to enhance junior dental students' learning, as the results of an assessment were better for novice students who used the 3D version compared to those who used the 2D tool. This difference was not observed when comparing the results of the two groups of third-year students. However, every participant, regardless of their year of study, enjoyed and appreciated having access to the 3D technological resources. Unfortunately, no similar studies have compared novices and more advanced participants when using 3D interactive models. However, there are studies conducted in the medical field which support the results obtained in this study (Tanagho et al., 2012; Prinz et al., 2005; Tan et al., 2012).

From the present findings it would seem that 3D interactive models and animations have the potential to help junior students to visualise and understand concepts. More advanced students do not benefit as much, as they can learn with a 3D model or with a 2D image. During the focus groups, third-year students were asked about their thoughts about the results. One of the participants indicated that it might be that experienced students already have the capacity to create a 3D model in their minds while watching 2D pictures, explaining: *"At this point, we have created a 3D model in our head from the 2D images we've seen along our study. So is like we are* *looking at the 2D but almost doing the 3D model in our head already. Whereas, the first years aren't at that stage yet so getting the actual 3D model was much more helpful and it comes from not visualising it in 3D already".* In other words, the student considered that more experienced students have the capacity to "create the 3D model" in their minds while learning. Thus, the 3D model was not as useful as it was for novice students.

The results of the questionnaire and the focus group sessions demonstrated that students highly valued the use of 3D interactive models. The majority of the participants agreed or strongly agreed that the resource and the 3D models were helpful for learning. These results are aligned with multiple studies assessing users' perception of 3D (Mitov et al., 2010; Maggio et al., 2012; Hamil et al., 2014; Soares et al., 2013; Vuchkova et al., 2011; Salajan et al., 2015; Papadopoulos et al., 2013). With the questionnaire findings there was no significant difference between the 2D and the 3D resource, demonstrating that both resources were highly valued by the participants. Overall, both versions of the TMJ iBook offered students a high-quality revision or study support material. However, once the results of the focus group were analysed, it was clearly established that all students preferred the 3D version. The possibility of "simplifying visualisation" and obtain "better orientation" when using the 3D models were the main reasons why participants preferred the 3D iBook. This deeper insight to the likes and dislikes of students showed that there is still space for improvements and the inclusion of more 3D resources for learning in dentistry.

Despite the positive results obtained in this study, the researcher recognises certain limitations. First, this part of the study included students from only one University. However, other results in this thesis showed no statistical difference between users from different Universities. Repeating the experiment with other students might be worthy to explore if the results are obtained are similar to the ones obtained.

Another limitation was the time and cost restrictions for the implementation of the 3D resources. Technology evolves rapidly, and cost is usually directly proportional to the degree of sophistication. Users of the 3D interactive resource in this study evaluated the specifications and characteristics positively. Additionally participants provide suggestions to improve the 3D models.

The final limitation relates to the timing of the assessment methods. In future research, it would be interesting to assess the learning outcomes of the users' several months after the use of the resource. This measurement has the potential to confirm if the learning process was anchored better by the use of 3D interactive models or 2D images. However, to isolate the experience and achieve a delayed testing design was beyond the scope of this study.

When the Tooth morphology iBook was produced, Collada files were used to display 3D models, as they allowed the user to fully interact with the model. However, technology evolved along with the progress of the PhD and a new method was selected to display the 3D models used in the temporomandibular joint iBook. The use of HTML links and Sketchfab platform allowed the research to include pre-set movements and tags to the 3D models. This change in how to incorporate the 3D models into iBooks is a clear example of how fast technology evolves. At the beginning of this project Collada file seemed to be the best option to offer an interactive 3D model to students. However, restrictions in the size of the files and the complexity of the models resulted in the use of Sketchfab, which accelerated the production process. As technology will continue to evolve in a high speed, it is important to keep up to-date on the new technologies and possibilities available.

10.8 CONCLUSIONS

This study suggests that the use of 3D interactive models have the potential to enhance TMJ learning of novice students and be a valuable resource for learning. This effect was greater for novice students compared to experienced learners. Additionally, the use of 3D learning materials seems to have a positive impact on students’ attitude towards learning regardless the level of experience of the student.

11 THE NEED FOR AND THE USE OF 3D DIMENSIONAL SIMULATION IN DENTAL EDUCATION - MY FINAL COMMENTS AND PERSONAL THOUGHTS.

Education and dental science are two areas of knowledge that are linked within the dental school, when passing information to your patients, and when continuing your professional development. Education and dentistry are strongly connected with the use of technology, a fact that motivated me to explore its impact in undergraduate dental education with special emphasis on three-dimensional (3D) technology.

Technology has progressed very fast and become very accessible; thus, separating it from education is a real challenge. Reviewing the literature confirmed the close link between technology and education. I found multiple documents describing different types of technological resources with an educational purpose. When reviewing the literature the biggest difficulty I found was to limit the information, even when focusing on 3D technology. I realised that the use of 3D technology was quite broad as it can be found in the form of images, animations, simulations and haptics. It can also be part of an e-learning educational package or a hands on training system.

There has been much written about the benefits of using 3D technology for education across many subjects and dentistry is no exception. Despite the large amount of information available, there is little evidence about their educational impact. This gap in the literature was the starting point for my PhD. Initially, I had multiple queries, such as: Is 3D technology beneficial for students? How do students perceive this type of technology? How does one produce a high quality learning resource containing 3D? What areas of dental education have most need of 3D? These questions became the basis for my research.

When planning my work, it seemed quite straightforward to answer my questions. Everything indicated that I needed an e-learning resource containing 3D material which I could test with students to measure the impact in their learning. However finding the ideal resource, suitable for dental students required more work.

The first thing I noticed when searching the literature was that in most reports where a 3D tool or learning package was described, little attention was placed on the learners need. This lack of inclusion of students' opinions was the main reason for the first study presented in this thesis. It also answered one of my questions "which areas of dental education would benefit from having a 3D learning resource?" I wanted to produce something that students needed, something useful, capable of making a real change in learning. To achieve that I needed to select a meaningful topic and justify its selection based on key stakeholders' thoughts and opinions including students, academics and graduates. I worked with four Universities to collect as much data as possible to obtain a clear idea which topic to choose when producing the new 3D learning tool. The results of this first study revealed that multiple areas of dentistry have a need for 3D in the form of animations, simulations and interactive models. Participants favoured clinical related topics over basic science topics.

Once I had the topic selected I needed to think how to create a resource containing 3D material. This would answer my second question "how to produce a high-quality learning resource containing 3D?" Receiving help from people experienced in medical art and computing science was paramount in accomplishing the design process. Finding the correct software was not an easy task, as there were several options available. Also, I needed to consider my lack of familiarity with these computer packages. Overall, I wanted to use an authoring software that anyone, regardless of their level of expertise, could use to produce an e-learning resource. After exploring alternatives I selected to work with iBooks Author. Mainly because the tool was simple to use, intuitive for unexperienced users, and it allowed me to produce high-quality e-learning materials. The key element that favoured this decision was that the software allowed the insertion of 3D interactive models without the need of been an e-learning expert. The biggest limitation of using iBooks and iBooks Author lies in the incompatibility of MacOs with other operating systems. However, this was not seen as an issue, as I had all the required devices to generate and run the package. Additionally, the Dundee Dental School has iPads that dental students can borrow and use during the testing and after finishing my research. It is important to remind the reader that my intention was not to test iBooks Author, iBooks or the use of iPads. Also, I did not intend to determine what the best authoring tool was. My central aim was to focus on the 3D technology contained in the package and assess its impact on learning.

At this stage, I had the topic and the authoring package for the construction of the e-learning resource. However, I needed to ensure an appropriate design. Therefore

I familiarised myself with the principles of e-learning and instructional design. Some of the principles varied from author to author in terms of names, but they were similar in terms of strategy. To provide educational value to the resource I used Gagne's nine steps for instructional design, because it was widely recognised and also was straightforward to follow. This step was very important to make sure that the resulting tool was not just something technological but had a strong educational basis.

Before designing the Temporomandibular Joint (TMJ) iBook, it seemed appropriate to test the reaction of potential users towards the use of the 3D models and the use of iBooks. To achieve this I needed a complete iBook containing several 3D models. As time was a limitation I decided to use a Tooth morphology iBook which had been partially developed in the Dundee Dental School. This seemed to be the ideal prototype as it addressed a key topic for dentistry. As the iBook was not absolutely finished, I had space to ensure that all the instructional design principles were part of it. However, most of the 3D models were completed, which saved a lot of time. One problem encountered when assembling the iBook was that some of the 3D model files were too large for the correct operation of the tablet. To solve this issue, the files were reduced in size and subsequently tested until the resource worked properly. Having close communication with the medical artist was a key element to successfully develop the resource. Although the technical work was conducted by the medical artist, I worked by his side to ensure the required outcome. Working together, as part of a team was very nourishing because it allowed me to learn the basics of 3D modelling, an area of knowledge distinct from dentistry. Even though my skills were not enough to produce a high-quality 3D model, the experience and knowledge I acquired will allow me to lead future projects involving 3D technology.

After finishing the Tooth morphology iBook, dental students tested the e-learning tool, and the results were used to inform and guide the development of the TMJ iBook. This answered another of my questions: “how do students perceive this type of technology?”. Exploring students’ perceptions confirmed that developing an iBook containing the 3D models was the correct option. In this stage I invited students from the University of Dundee and the University of The Andes, as both universities allowed me to work with their students. The experience demonstrated that the Tooth morphology iBook had the potential to enhance learning. Participants liked the resource, making several positive comments and suggestion for improvements. Only a few criticisms were received. Participants declared that they would use it for learning purposes mainly because of the 3D interactive models which were positively assessed. Prior to the experimental sessions I carefully planned the data collection. The experience with the Scottish participants was very straightforward, I provide them the iPads containing the iBook, as I used the devices of the faculty. However, the Chilean University did not have iPads available for students; so, I asked participants to bring their own devices. The challenge was to load the iBook in all the devices in a limited period of time.

Once I had the feedback from students about their use of the Tooth Morphology iBook, I was confident that using an iBook was the correct platform to test the use of 3D interactive models. For the TMJ iBook I opted for a simpler layout and the 3D models were added using an HTML link. HTML links were required as the size of the 3D files was larger than what iBooks Author supported. In this case the models were uploaded to Sketchfab, an online platform that allowed the models to be fully functional. The platform also allowed further features such as tags to be added as well as movements. Using Sketchfab was very beneficial because it meant that the size of a 3D model was no longer a limitation. Once the TMJ iBook was fully functional I needed to replicate it and produce a 2D version to assess the impact of the 3D technology. This second version contained images of the 3D models. The construction of the TMJ iBook again showed me the importance of team work, especially because the prototype had a complete new design. I worked side by side with the medical artist on the design and on the models I needed to represent the functional anatomy of the TMJ. Each chapter of the iBook was carefully designed and was based on the information and opinions collected from users. Now I had the e-learning resources and I was ready to explore the impact of 3D with students.

The final experimental stage of this project, answered my three last questions: Is 3D technology beneficial for students? What are the benefits? Who benefits? To answer these questions, I used a pre-test- post-test method, using a written assessment. I invited two groups of students, novices and more advanced. From the results, I extracted three conclusions. The first finding suggests that the use of 3D interactive models has a positive effect on learning. Secondly, that results of an assessment of novice students can be significantly better when using 3D interactive resources, outcomes that differ from the results observed from third-year students. The third conclusion indicates that dental students, regardless how experienced they are, perceive the use of 3D as a valuable resource for learning capable of influencing in their motivation and easing their visualisation of a structure.

The main limitation in this study was time. Producing 3D models is time consuming. However, time could potentially be reduced if more artists are involved in the production of the models. Of course this means higher costs. However, better learning should be a good justification for schools to produce similar 3D resources.

In future research, it would be interesting to analyse if the effects observed in learning due to 3D technology last over time. Reassessing students using a similar assessment tool after a considerable period would show if the learning was anchored in the students' long term memories.

After finishing this doctoral research, I can recommend that every dental school should have access to a technology department, composed of medical artists, photographers, IT experts; and led by a dentist. This would simplify and speed up the task of producing 3D technological resources for every department in the school. Also, I consider it important, that every dental academic has basic instruction in the use of 3D, and for them to be involved and aware in the production of new resources. Furthermore, students could potentially work in projects designing e-learning resources like the ones presented in this doctoral research. This would help them with their learning and would accelerate the construction of new resources.

This doctoral research has had a huge impact in my professional and personal life. From a professional point of view, this PhD has been my first formal steps within education. One of my personal goals has always been to become a clinical teacher or a professor, however once I finished my master degree in Prosthodontics I was not ready to deal with an educational career. I needed some educational background to understand the “learning process” and discover how to become a “good educator”. To deal with my lack of instruction in education, before starting my PhD I took a medical education certificate course. This course provide me with the basics about education and educational research. After accomplishing four modules my whole perspective and understanding of education was changed. While I progressed in my course I realise how naive I was before, when I had the impression that education was simply the process of teaching something to someone. Definitely my experience and knowledge about education has had an exponential growth in the last few years. However, even now, after accomplishing my whole project I think that I still have a long way to learn to achieve my goal of becoming that inspiring professor.

The professional skills that the PhD process has provided me with included an abundant set of IT skills which include proficient management of Microsoft Office package, Nvivo, iBook Author, Camtasia and Qiqqa. It also allowed me to acquire basic knowledge about 3D modelling and management of package such as ZBrush, Maya and Adobe.

My research skills and management of databases such a Scopus and Medline has also be enhanced because of the process. Now I am able to design measuring tools and plan successful experimental settings, which can be transferable to other investigations and areas of research. This experience gave me the opportunity to experiment with various research methods as well as preform qualitative and quantitative data analysis.

During these years, I had the opportunity to share my work with other colleagues from around the world as I presented my work in several national and international conferences. Without a question, these occasions reinforced my presentations skills and become a valuable network opportunity.

The PhD has also allowed me to acquire valuable soft skills that I will be able to apply in any future working scenario. During this doctoral study I had the chance to conduct collaborative work with different members of the faculty, including academics, students and administrative staff. Without a doubt my communications skills had been boosted as well as my management abilities when acting as a team player or when leading my research interventions. Additionally, the PhD enhanced my problem solving skills and increased my capacity to pay attention to details.

The contact with students showed me that sometimes it can be challenging to bond with them. However, demonstrating self-confidence was a key element to achieve the connection I needed to explore their thoughts. The experience of working with students provided me with insight on their behaviour and expectations and also re-established myself as a learner, experience which I will be able to transfer to my future teaching.

During my studies my personal life also experienced important changes. My two dear sons were born in this period, a fact that tested my organisational skills and taught me how to work under pressure. Balancing family life and work has been a challenge, however I proved to myself that I have the multitasking capacity you need nowadays if you want to raise a family and work. In practice, I learned how to manage my time and become proficient, making the most of any silent moment. I also learned how to deal with procrastination and how to stay away from social media to avoid distractions.

There were difficult moments where everything seems stuck and some others where I did not have an answer to everyone's favourite question: when are you finishing? However, having the support, feedback and guidance of my supervisors helped me to overcome those moments. The support of my family, especially of my husband, was also very important to succeed in this process. Despite all the challenging moments, I can happily say that my PhD journey has been full of gratifying experiences and exciting challenges. Being a PhD student has open my mind in so many aspects that it has changed me as a person in a positive way.

Finally I can state that this thesis describes the complete process of assessing the impact of 3D models for dental education. The final message I would like to reinforce is that 3D has the potential to enhance students learning. Therefore, it is our duty to deliver this type of tools to ensure that students receive the best possible education, resulting in better dental practice and better oral health in our community.

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APPENDIX 1: FOCUS GROUP PROTOCOL

Focus group protocol

- Type of Focus group design: Multiple-category
- Duration of the session: 35 minutes
- Room: Isla room in the Franklin Building
- Date: to be confirmed
- Participants per session: 6
- Ideal umber of sessions: 2
- Recruitment of students: students will be offered to take part and voluntaries are going to be considered. Voluntaries are going to receive an information document about the focus session and the project on that day.
- Incentive: a pizza lunch can be offered. (10 pizzas, 5 per session)
- Materials needed for the session:
    - Voice Recorder
    - Consent forms for signature in case
    - Clock
    - 6 iPad with the New Tooth Morphology iBook.

Session schedule

- Opening (5min)
    - Introduction of myself
    - Brief explanation of the aims of the project
    - Ground rules
    - Reminder of free participation and getting written consent
- Body (30-40 min)
    - The first question that is going to be use to open the session will be: Did you like the iBook? A very general question that then is going to lead to the following queries:
        - Why did you like it?
        - Is this resource you are likely to use for studying purposes?
        - What do you think it could be modified? (if no answers are obtained, then I will start recalling the responses obtained in the questionnaire in relation to improvement or changes suggested.)
        - Choose key questions of the questionnaire and ask them their thoughts about the highest frequency answer obtained.
        - Show the group a new version of the Tooth Morphology improved and see if that satisfy the needs of students.
        - Ask for any further comments
        - End with the last question: do you think this type of resource might improve your learning?
- Closure (5 min)
    - Closure and thanking for taking part

Next steps: Do a pilot session with postgraduates students

APPENDIX 2: INFORMATION SHEET TEMPLATE USED FOR STUDY 1, 2 AND 3

Participant Information Sheet
Version 1.0 – Date 17/06/13

Identifying areas of need for three-dimensional learning resources in dental education

Before deciding to participate in this research we encourage you to read carefully this information sheet. In case of any further queries please do not hesitate in contacting the main researcher (contact details below). If you decide not to take part there will be no disadvantage to you of any kind. If you agree to participate we welcome and thank you.

This study is the first phase of a PhD project, undertaken as part of an educational qualification by the postgraduate student Paulina Poblete under the supervision of: Professor Samuel Cadden, Dr Andrew Forgie, Dr. Andrew Mason form the Dental School of University of Dundee and Dr. Sean McAleer, from the Centre for Medical Education of University of Dundee.

What is the aim of this research?
This study aims to identify areas of dentistry that would benefit from 3D learning virtual animation or simulation resource.

Why I was selected as a possible participant?
Because we took a random sample of 5-6 dental students from your year and your name was selected.

Do I have to participate because I was selected?
No, you can either accept or decline. Your participation is totally voluntary.

Can I change my mind and withdraw my participation from the project at a later date?
Yes, you may withdraw at any time without any disadvantage to yourself.

What information will be collected and how it will be collected?
In this stage the data will be collected by means of a focus groups session. The idea is to collect a list of knowledge components and skills (concepts) which you think would benefit from a 3D virtual animation/simulation as a learning resource. The data will be transcribed during the session to a paper sheet and it will be kept by the main researcher until de end of the project, then it will be destroyed. There will no audio or video recording during the session. The focus group session should last about 30-45minutes and all your responses will be anonymous.

What are you going to ask me?
The question asked will be: what are the knowledge component and skills that would benefit from being taught using a 3D virtual format?

How else is going to be in the session?
Five other classmates of yours will be invited to take part. The main research will lead the session and arrange a suitable time to meet.

What will happen to the information collected in the study?
All the information collected will be used to produce a survey. This survey will be sent to dental students and academics of the Universities of Glasgow, Aberdeen, Dundee and The Andes (Chile).

If I have further questions whom I should contact?
Paulina Poblete.
Telephone number: 01382 383063
Email: p.i.pobletepacheco@dundee.ac.uk
Address: 8th floor postgraduate Hub. Dental School University of Dundee.

APPENDIX 3: CONSENT FORM STUDY CHAPTER 3

Identifying areas of need for three-dimensional learning resources in dental education

Consent form for participants

I have read and understand the participant information sheet version 1.1 date 17/06/13 regarding this project. I recognise that I am free to request further information at any stage and at the moment all my questions have been answered to my satisfaction.

Therefore, I declare that:

1.	My participation in the project is entirely voluntary.	YES/NO
2.	I am free to withdraw from the project at any time without explanation and without any disadvantage.	YES/NO
3.	I understand that there are no financial or material benefits for my participation.	YES/NO
4.	I agree to participate in this study, which will involve my participation in a focus group.	YES/NO

_______________________ Name of participant

_______________ Date

________________ Signature

_______________________ E-mail

_______________________ Researcher

_______________ Date

________________ Signature

Page 1/1

This project has been reviewed and approved by the University of Dundee Human Research Ethics Committee

APPENDIX 4: FINAL LIST OF THE 97 ITEMS IN ALPHABETIC ORDER

Absorption of nutrients, from the gut and transport to the tissues
Amalgam setting
Anatomy and Physiology of the heart including how the Ventricles work
Anatomy of the Cardiovascular system
Anatomy of the larynx
Anatomy of the TMJ space
Anatomy of trigeminal nerve
Basic Cellular anatomy and structures
Biomechanics in orthodontics (tooth movement)
Caries formation
Caries removal including tactile feedback
Cavernous sinus and cerebellum anatomy
Cell mitosis and meiosis
Circulatory system - blood flow in the body from lungs to tissues
Composite setting
Concepts in occlusion such as Bennett angle, Bennett movement, condylar guidance, anterior guide, excursive movements
Consequences of plaque over hard and soft tissues
Course of cranial nerves until the innervated tissues
Dental instruments functions, for example the periodontal scaling instruments
Dentine bonding
Denture design - 3D model to design cobalt-chrome dentures
Development of the dental arch
Disease propagation through the body
DNA double helix
Drugs clearance methods
Ear anatomy model
Effect of drugs on the inflammatory process
Embryological development of the palate
Exchange of oxygen in the alveolus
Extraction techniques: movements and force to extract the tooth
Eye anatomy including muscles and nerves
Facial imaging
Fine needle aspiration
Flap design
Functions of Mitochondria and Golgi complexes
Glass ionomer setting

Head and Neck anatomy
Head and neck growth and development
Hormonal cycles. From hormone production to their action
Impact of alcohol and tobacco in oral mucosa
Impacted tooth identification and extraction techniques
Indirect vision practice model
Instrumentation of deep pockets
Kidney anatomy
Le Fort fractures
Local anaesthesia techniques including the needle position, the tissues and how the needle passes through or close to.
Mandibular and maxillary development, growth and anatomy
Mandibular fracture
Mastication process
Masticatory Muscles anatomy and physiology
Mechanisms of action of antibiotics
Metabolic reactions- Pathways of chemical reactions represented as interactive models
Model explaining composite bonding to enamel -- acid etching process
Model in 3D of oral cancer development and progress
Model representing the gag reflex
Model representing the process of infections spread
Model showing most common errors and bad decision making for restorative dentistry (e.g. errors in prosthesis design, errors in crown preparation)
Model to practice how to do Wax build up
Molecular interaction of amino acids synthesis
Most common oral pathology lesions
Muscle contraction process
Nerve action potentials
Neuroanatomy central and peripheral
Normal movements of the jaw and pathological movement
Occlusion functioning and types
Orthodontics - appliance design
Orthognathic surgery including for example: Decompensation in orthognathic surgery
Pain Pathways
Pathogenesis of diseases
Pathology of Tooth development including for example Amelogenesis imperfecta
Periodontal ligament structure
Periradicular surgery
Pharmacology - models of how drugs work in the tissues

Physiology of the GI tract
Plaque and Biofilm formation
Pocket formation and ulceration of the tissues due to plaque formation
Process of enamel remineralisation using Fluoride
Process of ossification and types of ossification
Protein synthesis
Removal of large lesions such as cysts
Renal physiology
Respiratory System model, including process of ventilation, perfusion
Root canal treatment model representing happens inside the canal and how to determinate the working length
Salivary glands physiplogy, micro and macro anatomy
Serial extractions
Space infections of the head and neck
Surgical procedures for implants
Suturing techniques
Teeth chart to record full treatments
Third molar extractions
TMJ dysfunction; including for example Clicking Temporomandibular Joints
Tooth anatomy and tooth physical properties
Tooth and cavity preparation for crowns, onlays, inlays, ¾ crowns, endondontic access
Tooth development from beginning to eruption
Use of Elevators
Virtual dental articulator
Virtual study models

APPENDIX 5: COMPLETE SURVEY SECTION 2 CHAPTER 3

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Declaration

Before continuing please make sure you have read and understood the Information sheet attached to the invitation email or click the "MORE INFORMATION" box to access it.

1. I declare that my participation in this project is voluntary. Also, I have read and understood the information sheet provided.

More Info

- ○ I agree, I want to continue with the survey.
- ○ I do not agree, I do not want to take part in the survey. (If this option is selected please close your window to leave the survey)

Continue >

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Welcome!

Thank you for taking part in this survey! It should take less than 10 minutes of your time.

Once again many thanks for your time and cooperation!

Continue >

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Identifying areas of need of three-dimensional learning resources in dental education.

2. Please rate the following areas from 1 to 5 based on the benefit of a virtual 3D resource for dental education.

	Minimum benefit 1 2 3 4 5 Maximum benefit				
	1	2	3	4	5
a. Absorption of nutrients, from the gut and transport to the tissues	○	○	○	○	○
b. Amalgam setting	○	○	○	○	○
c. Anatomy of the Cardiovascular system	○	○	○	○	○
d. Anatomy and Physiology of the heart including how the Ventricles work	○	○	○	○	○
e. Anatomy of the larynx	○	○	○	○	○
f. Anatomy of the TMJ space	○	○	○	○	○
g. Anatomy of trigeminal nerve	○	○	○	○	○
h. Basic Cellular anatomy and structures	○	○	○	○	○
i. Biomechanics in orthodontics (tooth movement)	○	○	○	○	○
j. Caries formation	○	○	○	○	○
k. Caries removal including tactile feedback	○	○	○	○	○
l. Cavernous sinus and cerebellum anatomy	○	○	○	○	○
m. Cavity Preparation	○	○	○	○	○
n. Cell mitosis and meiosis	○	○	○	○	○
o. Circulatory system - blood flow in the body from lungs to tissues	○	○	○	○	○
p. Composite setting	○	○	○	○	○
q. Concepts in occlusion such as Bennett angle, Bennett movement, condylar guidance, anterior guide, excursive movements	○	○	○	○	○
r. Consequences of plaque over hard and soft tissues	○	○	○	○	○
s. Course of cranial nerves until the innervated tissues	○	○	○	○	○
t. Crown preparation	○	○	○	○	○

Continue >

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Identifying areas of need of three-dimensional learning resources in dental education.

3.

	Minimum benefit 1 2 3 4 5 Maximum benefit				
	1	2	3	4	5
a. Dental instruments functions, for example the periodontal scaling instruments	○	○	○	○	○
b. Dentine bonding	○	○	○	○	○
c. Denture design - 3D model to design cobalt-chrome dentures	○	○	○	○	○
d. Development of the dental arch	○	○	○	○	○
e. Disease propagation through the body	○	○	○	○	○
f. DNA double helix	○	○	○	○	○
g. Drugs clearance methods	○	○	○	○	○
h. Ear anatomy model	○	○	○	○	○
i. Effect of drugs on the inflammatory process	○	○	○	○	○
j. Embryological development of the palate	○	○	○	○	○
k. Exchange of oxygen in the alveolus	○	○	○	○	○
l. Extraction techniques: movements and force to extract the tooth	○	○	○	○	○
m. Eye anatomy including muscles and nerves	○	○	○	○	○
n. Facial imaging	○	○	○	○	○
o. Fine needle aspiration	○	○	○	○	○
p. Flap design	○	○	○	○	○
q. Functions of Mitochondria and Golgi complexes	○	○	○	○	○
r. Glass ionomer setting	○	○	○	○	○
s. Head and Neck anatomy	○	○	○	○	○
t. Head and neck growth and development	○	○	○	○	○

Continue >

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Identifying areas of need of three-dimensional learning resources in dental education.

4.

	Minimum benefit 1 2 3 4 5 Maximum benefit				
	1	2	3	4	5
a. Most common oral pathology lesions					
b. Muscle contraction process					
c. Nerve action potentials					
d. Nerve pathways in the mandible					
e. Neuroanatomy central and peripheral					
f. Normal movements of the jaw and pathological movement					
g. Occlusion functioning and types					
h. Orthodontics - appliance design					
i. Orthognathic surgery including for example: Decompensation in orthognathic surgery					
j. Pathogenesis of diseases					
k. Pathology of Tooth development including for example Amelogenesis imperfecta					
l. Periodontal ligament structure					
m. Periradicular surgery					
n. Pharmacology - models of how drugs work in the tissues					
o. Physiology of the GI tract					
p. Plaque and Biofilm formation					
q. Pocket formation and ulceration of the tissues due to plaque formation					
r. Process of enamel remineralisation using Fluoride					
s. Process of ossification and types of ossification					
t. Protein synthesis					

Continue >

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Identifying areas of need of three-dimensional learning resources in dental education.

5.

	Minimum benefit 1 2 3 4 5 Maximum benefit				
	1	2	3	4	5
a. Hormonal cycles. From hormone production to their action					
b. Impact of alcohol and tobacco in oral mucosa					
c. Impacted tooth identification and extraction techniques					
d. Indirect vision practice model					
e. Instrumentation of deep pockets					
f. Kidney anatomy					
g. Le Fort fractures					
h. Local anaesthesia techniques including the needle position and the tissues the needle passes through or close to.					
i. Mandibular and maxillary development and growth					
j. Mandibular fracture					
k. Mastication process					
l. Masticatory Muscles anatomy and physiology					
m. Mechanisms of action of antibiotics					
n. Metabolic reactions- Pathways of chemical reactions represented as interactive models					
o. Model explaining composite bonding to enamel -- acid etching process					
p. Model in 3D of oral cancer development and progress					
q. Model representing the process of infections spread					
r. Model showing most common errors and bad decision making for restorative dentistry (e.g. errors in prosthesis design, errors in crown preparation)					
s. Model to practice how to do Wax build up					
t. Molecular interaction of amino acids synthesis					

Continue >

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Identifying areas of need of three-dimensional learning resources in dental education.

6.

	Minimum benefit 1 2 3 4 5 Maximum benefit				
	1	2	3	4	5
a. Removal of large lesions such as cysts	○	○	○	○	○
b. Renal physiology	○	○	○	○	○
c. Respiratory System model, including process of ventilation, perfusion	○	○	○	○	○
d. Root canal treatment model representing happens inside the canal and how to determinate the working length	○	○	○	○	○
e. Serial extractions	○	○	○	○	○
f. Space infections of the head and neck	○	○	○	○	○
g. Surgical procedures for implants	○	○	○	○	○
h. Suturing techniques	○	○	○	○	○
i. Syndromes and tooth development comparing normal with abnormal	○	○	○	○	○
j. Teeth chart to record full treatments	○	○	○	○	○
k. Third molar extractions	○	○	○	○	○
l. TMJ dysfunction; including for example Clicking Temporomandibular Joints	○	○	○	○	○
m. Tooth anatomy and tooth physical properties	○	○	○	○	○
n. Tooth development from beginning to eruption	○	○	○	○	○
o. Tooth development including amelogenesis	○	○	○	○	○
p. Tooth preparation for crowns, onlays, inlays, ¾ crowns	○	○	○	○	○
q. Use of Elevators	○	○	○	○	○
r. Virtual dental articulator	○	○	○	○	○
s. Virtual study models	○	○	○	○	○

7. What other areas of dentistry do you think would benefit from a 3D virtual resource? *(Optional)*

8. Please provide the following information about you.

i. Gender
Select an answer

ii. Please choose from the following statements?
Select an answer

9. Do you want to take part in the prize draw?

More Info

○ Yes ○ No
If Yes, please provide contact details. Complete name and email.

Continue >

3D For Dental Education

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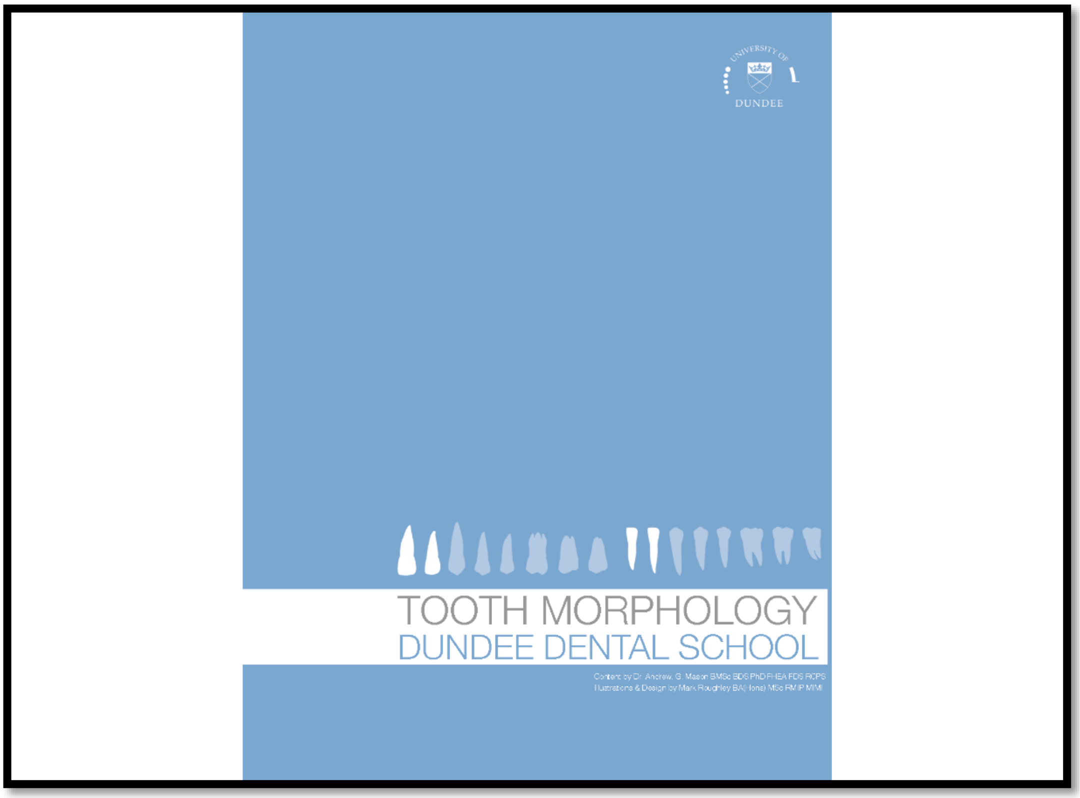
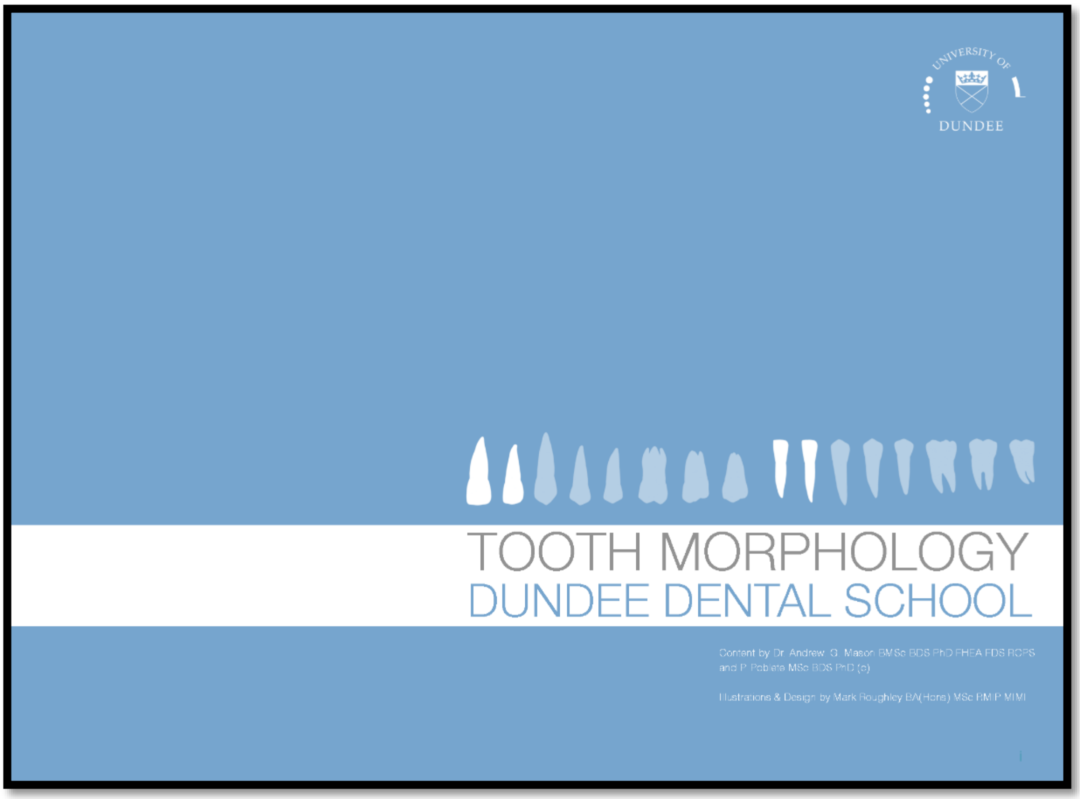
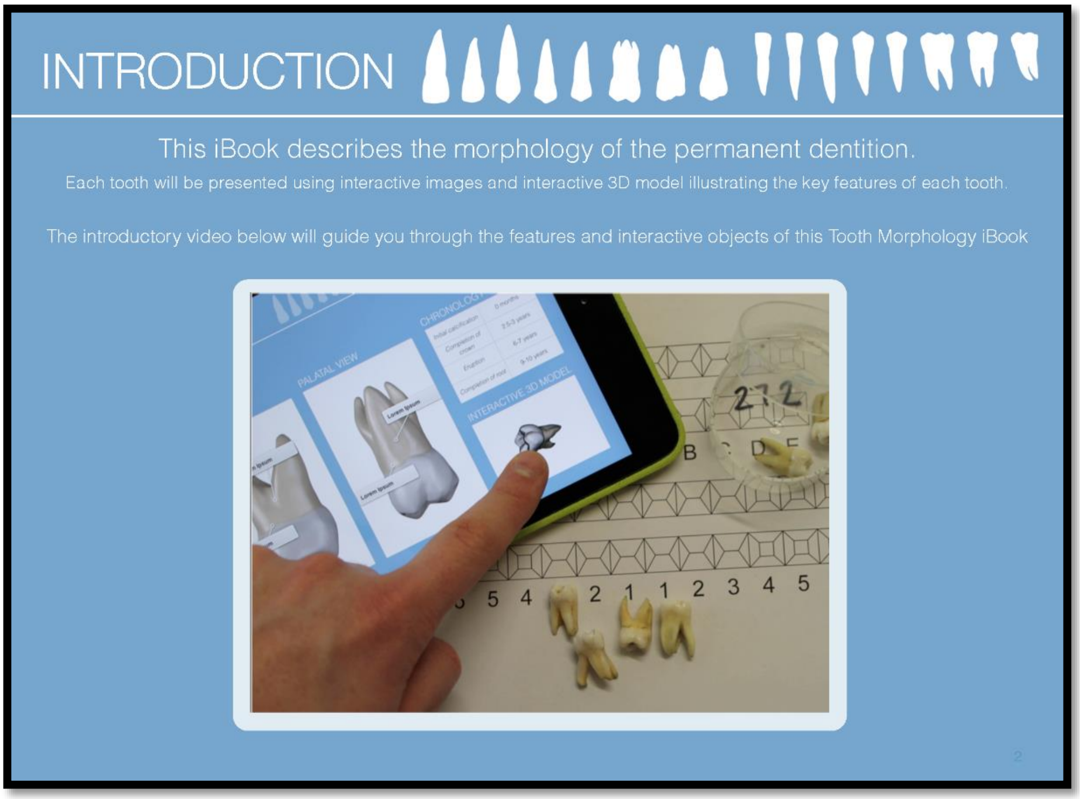
Thank you and Good Luck!

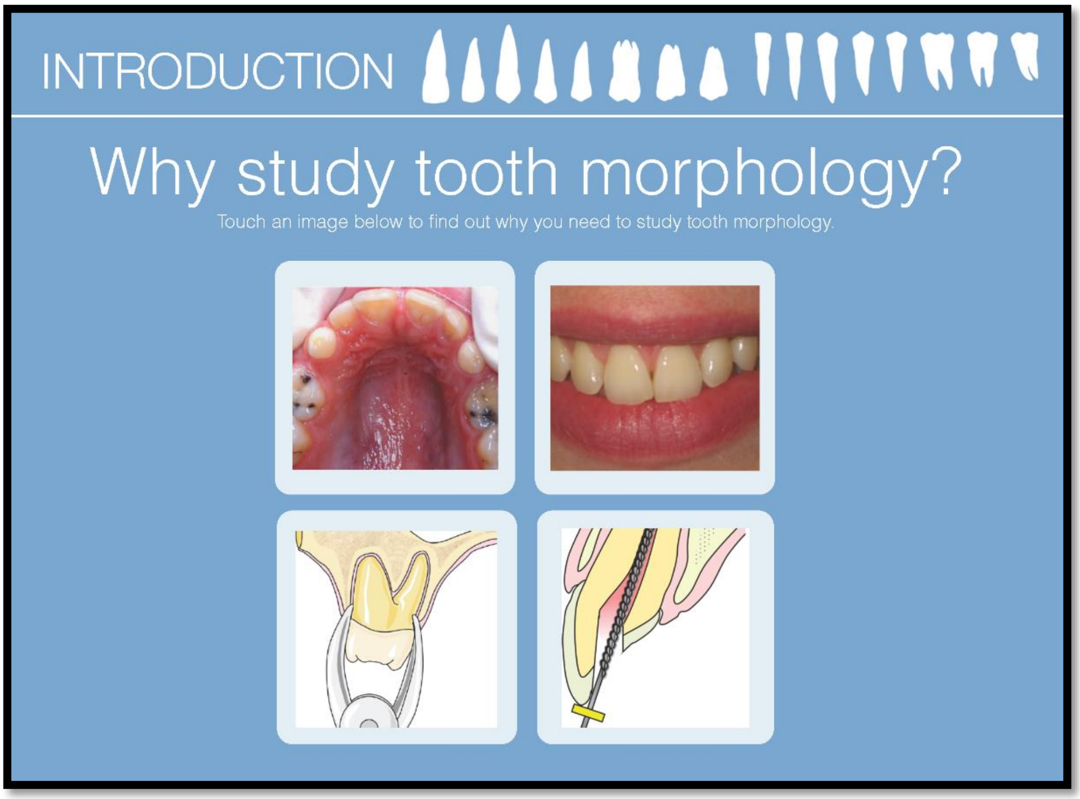
Edit this page

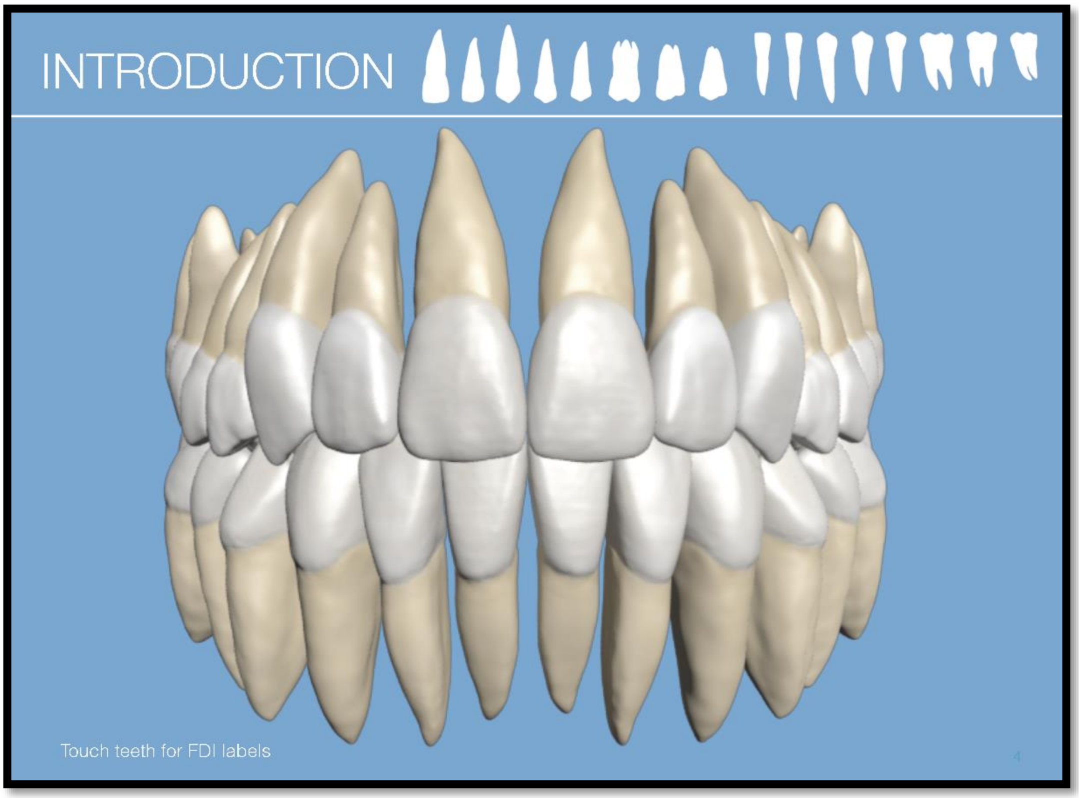
APPENDIX 6: THE TOOTH MORPHOLOGY IBOOK

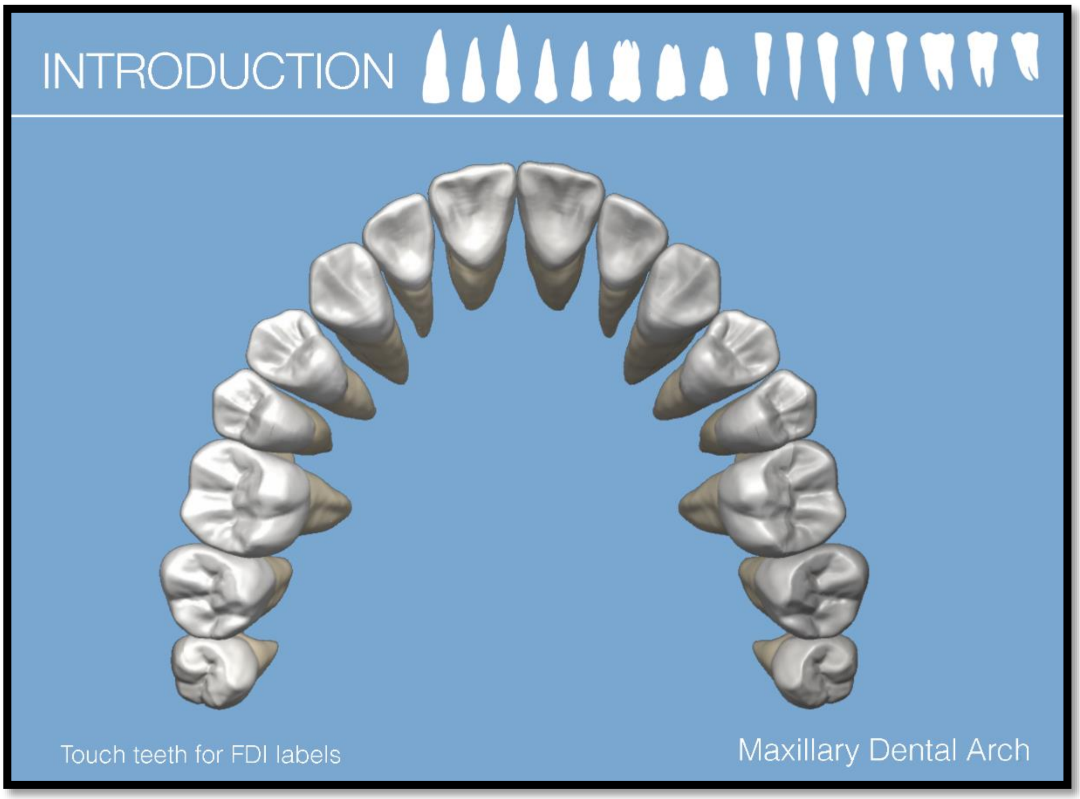


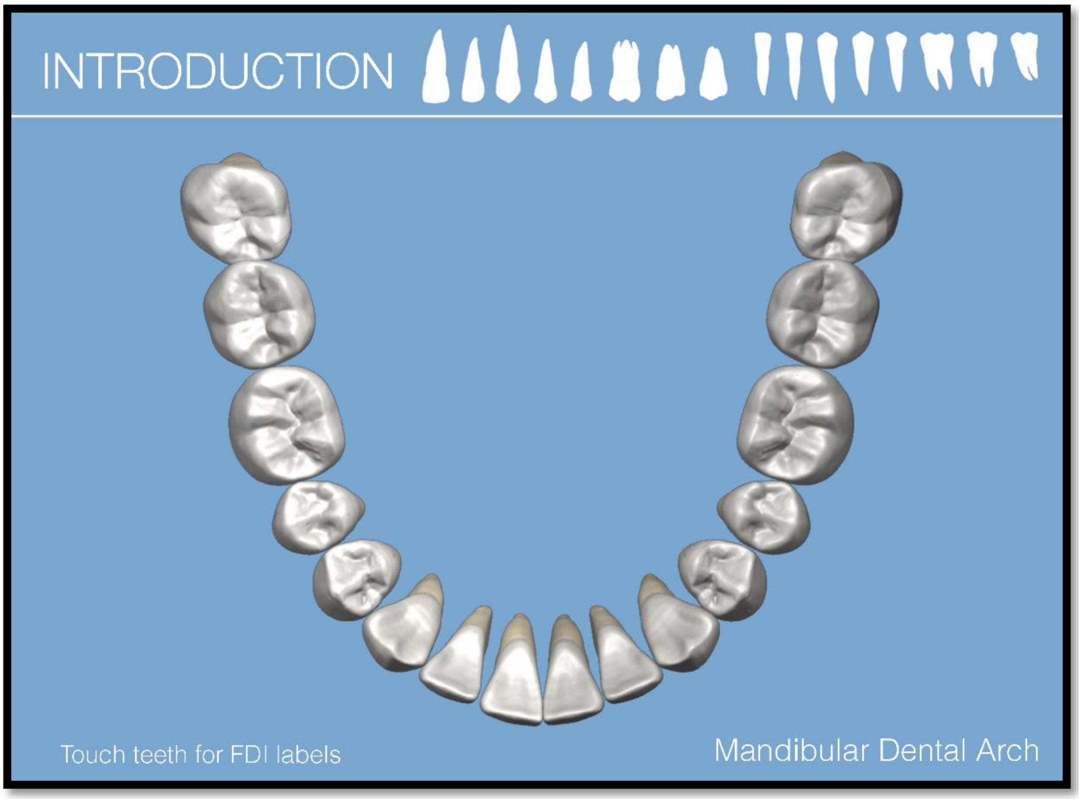


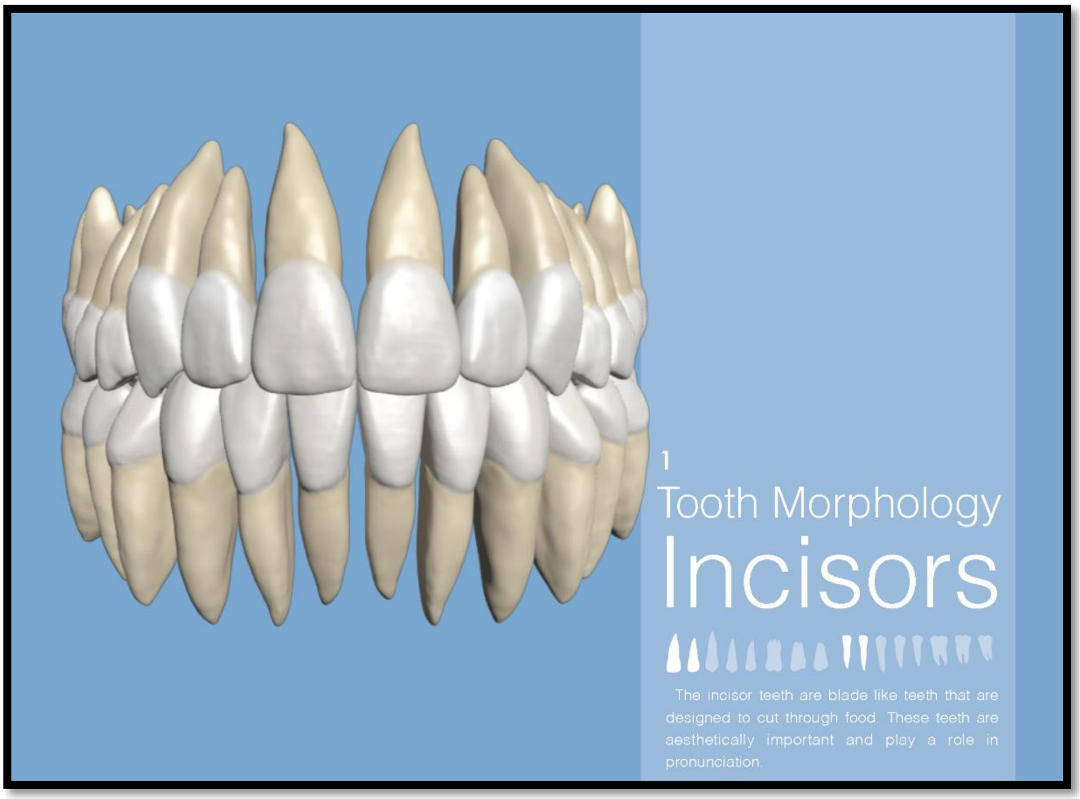

INTRODUCTION
This iBook describes the morphology of the permanent dentition.
Each tooth will be presented using interactive images and interactive 3D model illustrating the key features of each tooth.
The introductory video below will guide you through the features and interactive objects of this Tooth Morphology iBook

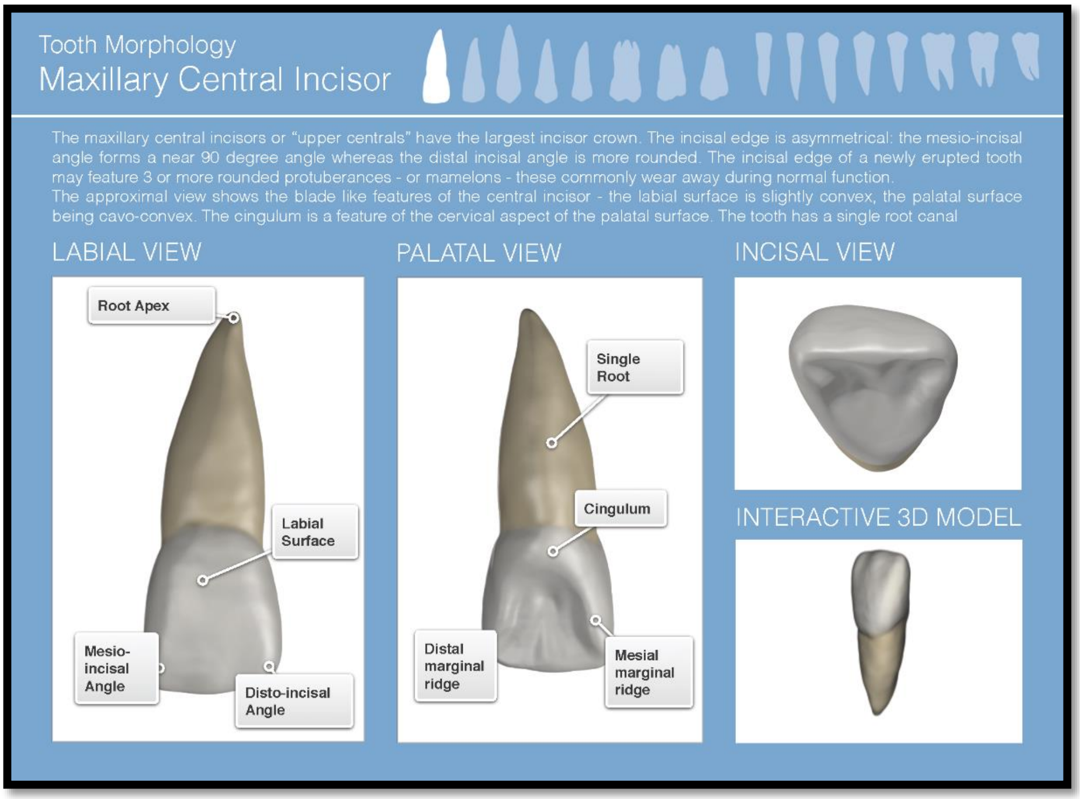

INTRODUCTION
Why study tooth morphology?
Touch an image below to find out why you need to study tooth morphology.

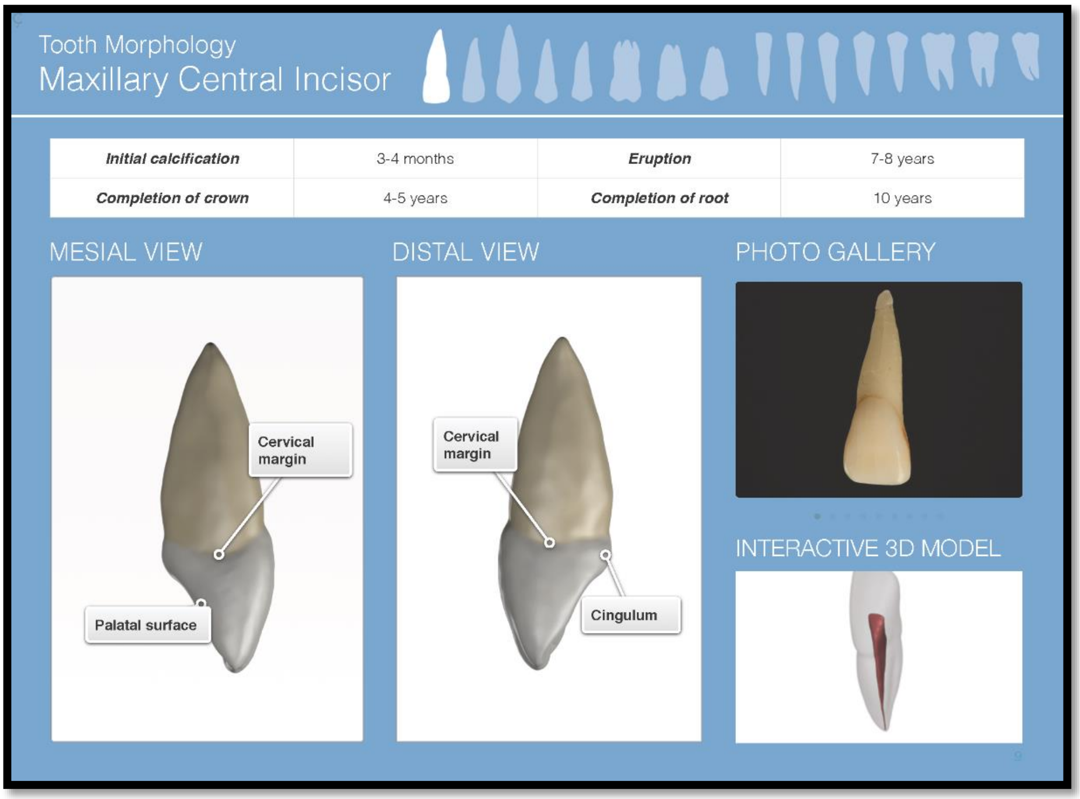

INTRODUCTION
Touch teeth for FDI labels

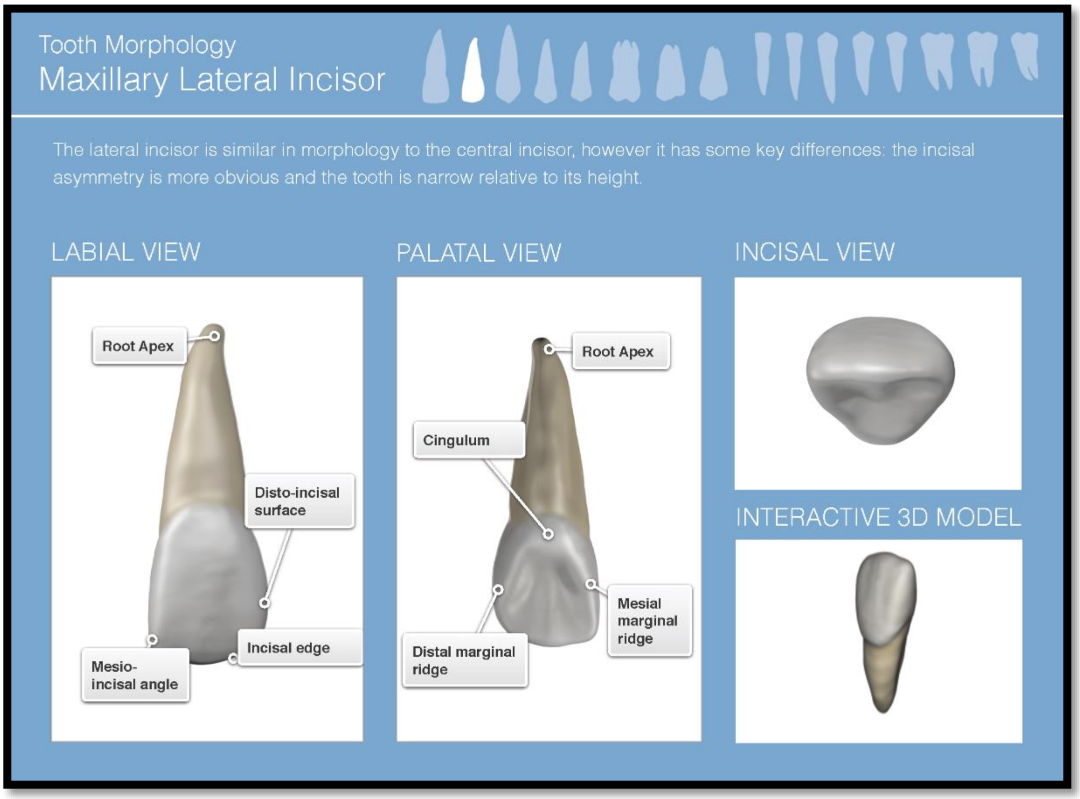

INTRODUCTION
Touch teeth for FDI labels
Maxillary Dental Arch

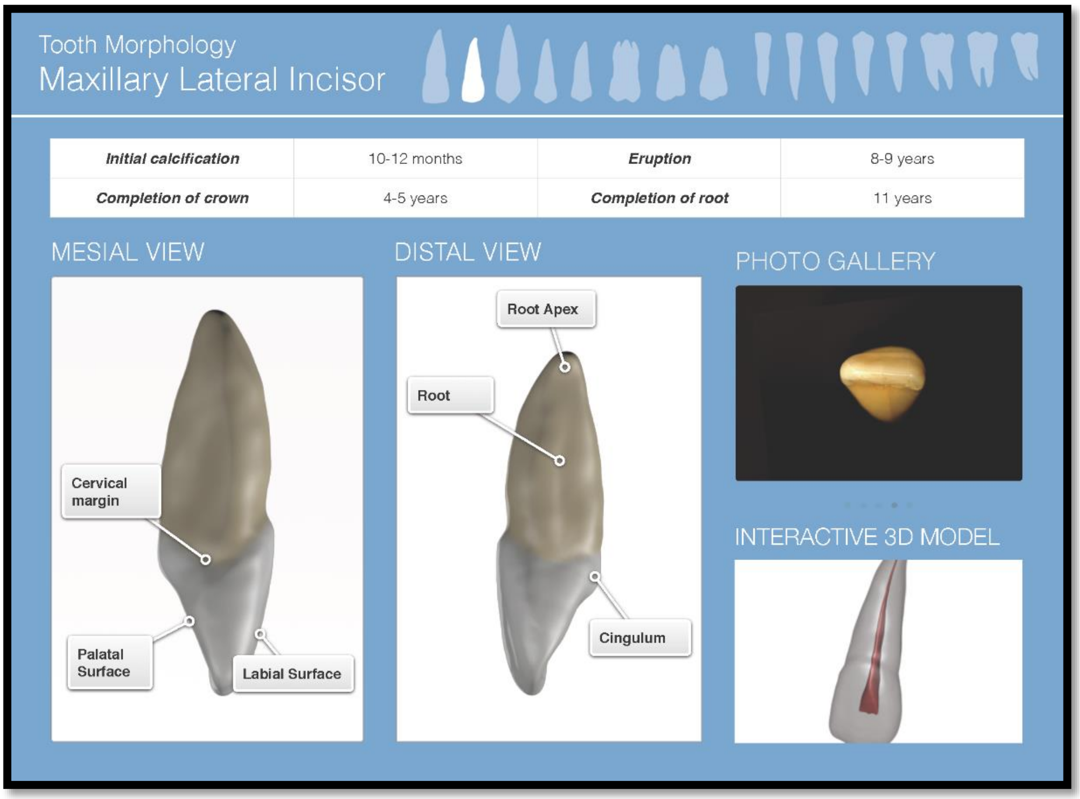

INTRODUCTION
Touch teeth for FDI labels
Mandibular Dental Arch

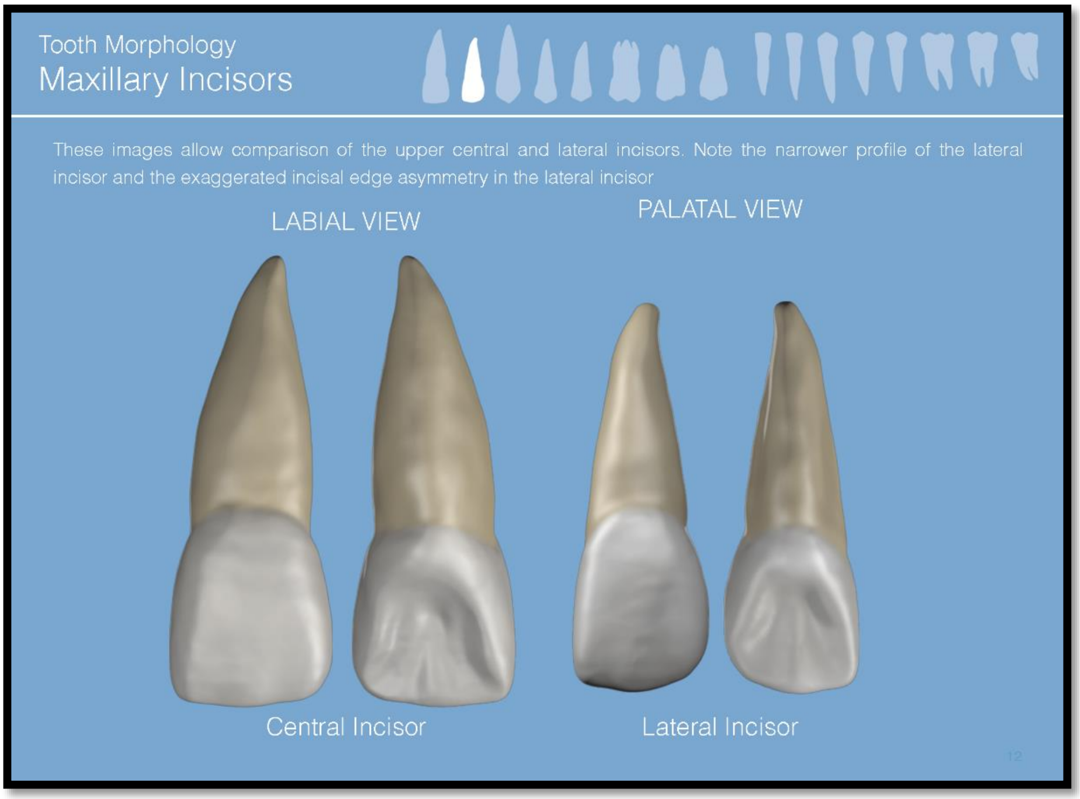

1
Tooth Morphology
Incisors
The incisor teeth are blade like teeth that are designed to cut through food. These teeth are aesthetically important and play a role in pronunciation.

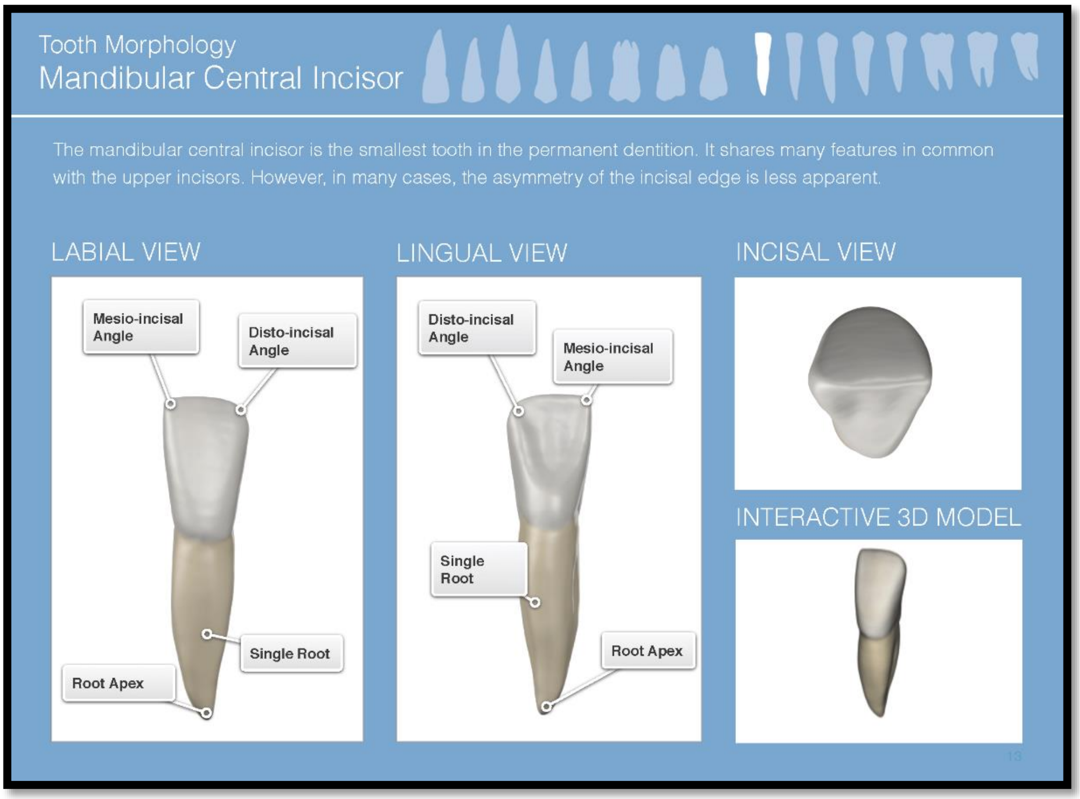

Tooth Morphology
Maxillary Central Incisor
The maxillary central incisors or "upper centrals" have the largest incisor crown. The incisal edge is asymmetrical: the mesio-incisal angle forms a near 90 degree angle whereas the distal incisal angle is more rounded. The incisal edge of a newly erupted tooth may feature 3 or more rounded protuberances - or mamelons - these commonly wear away during normal function.
The approximal view shows the blade like features of the central incisor - the labial surface is slightly convex, the palatal surface being cavo-convex. The cingulum is a feature of the cervical aspect of the palatal surface. The tooth has a single root canal
LABIAL VIEW
Root Apex
Labial Surface
Mesio-incisal Angle
Disto-incisal Angle
PALATAL VIEW
Single Root
Cingulum
Distal marginal ridge
Mesial marginal ridge
INCISAL VIEW
INTERACTIVE 3D MODEL

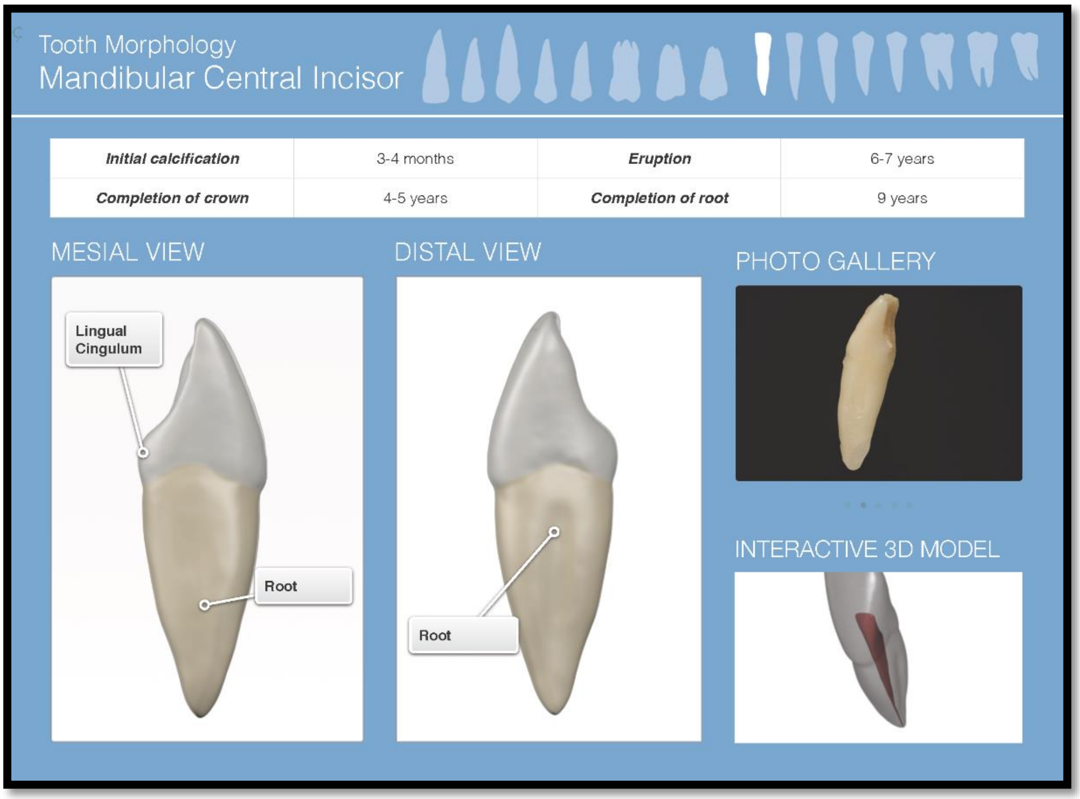

Tooth Morphology
Maxillary Central Incisor
Initial calcification
3-4 months
Eruption
7-8 years
Completion of crown
4-5 years
Completion of root
10 years
MESIAL VIEW
Cervical margin
Palatal surface
DISTAL VIEW
Cervical margin
Cingulum
PHOTO GALLERY
INTERACTIVE 3D MODEL

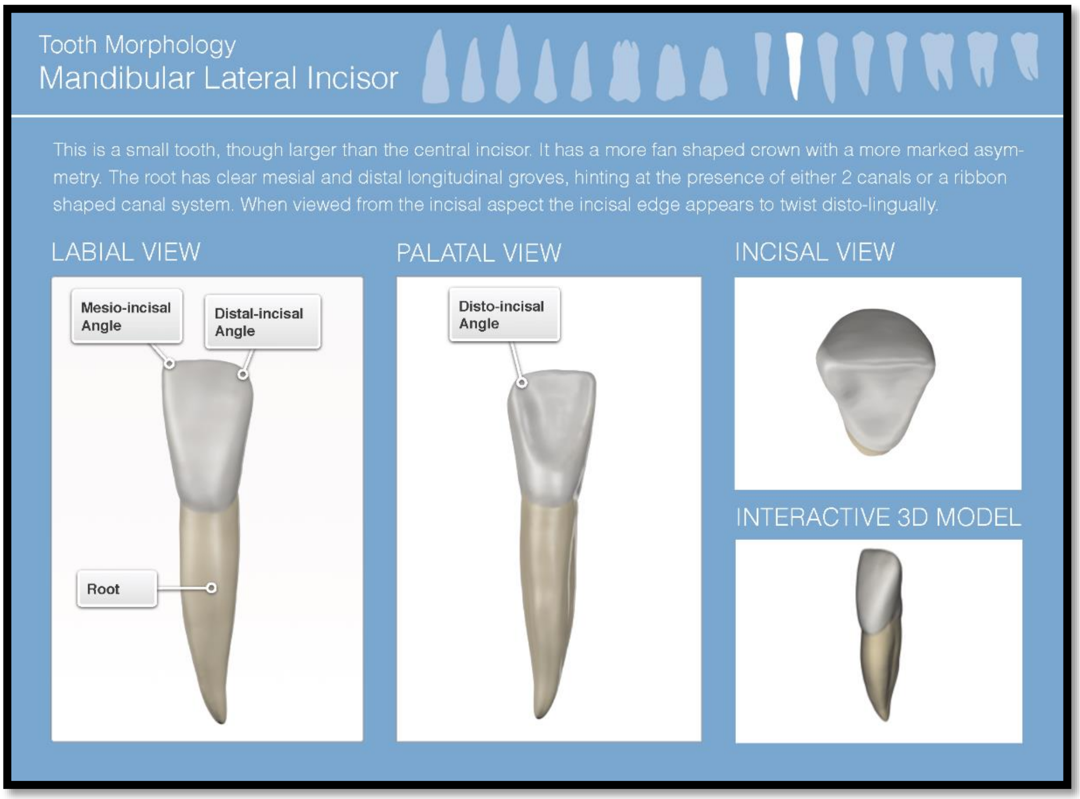

Tooth Morphology
Maxillary Lateral Incisor
The lateral incisor is similar in morphology to the central incisor, however it has some key differences: the incisal asymmetry is more obvious and the tooth is narrow relative to its height.
LABIAL VIEW
Root Apex
Disto-incisal surface
Incisal edge
Mesio-incisal angle
PALATAL VIEW
Root Apex
Cingulum
Mesial marginal ridge
Distal marginal ridge
INCISAL VIEW
INTERACTIVE 3D MODEL

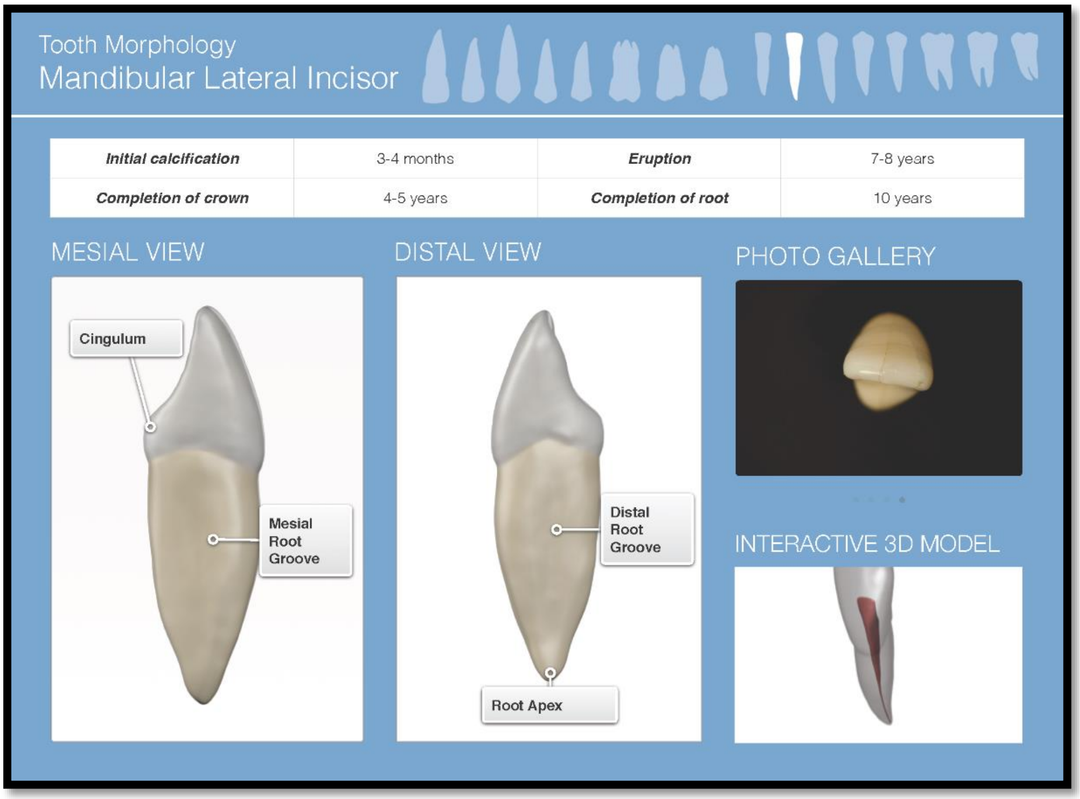

Tooth Morphology
Maxillary Lateral Incisor
Initial calcification
10-12 months
Eruption
8-9 years
Completion of crown
4-5 years
Completion of root
11 years
MESIAL VIEW
Cervical margin
Palatal Surface
Labial Surface
DISTAL VIEW
Root Apex
Root
Cingulum
PHOTO GALLERY
INTERACTIVE 3D MODEL

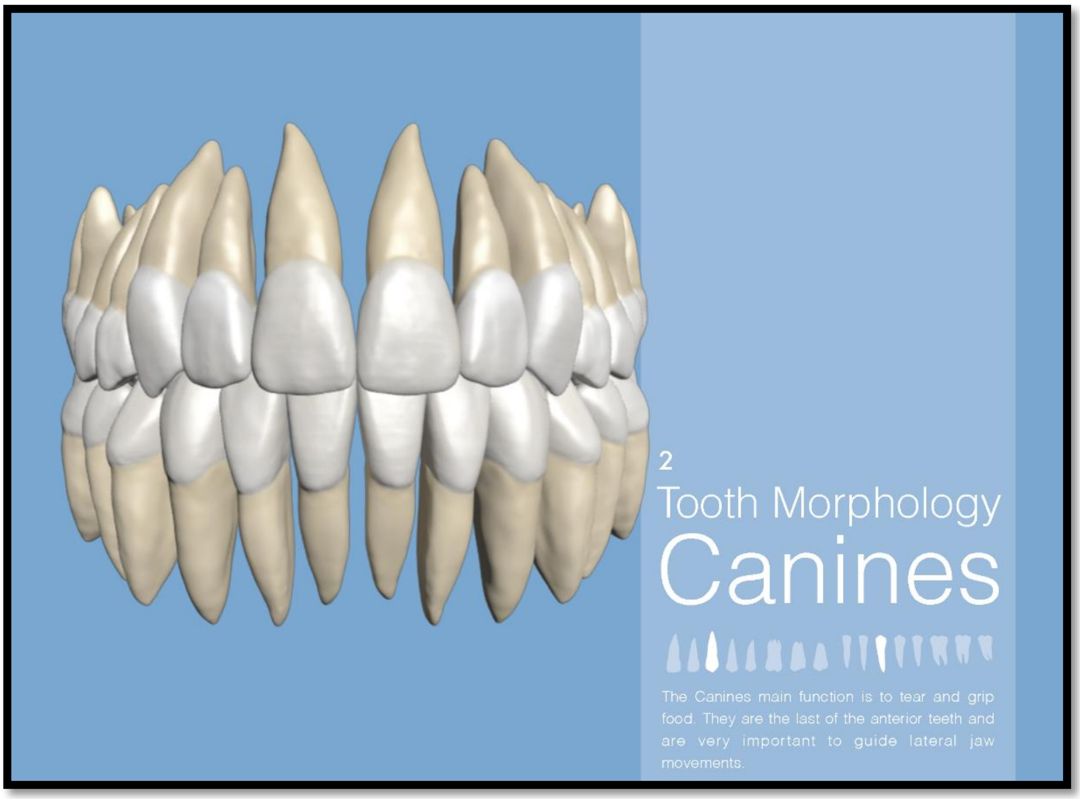

Tooth Morphology
Maxillary Incisors
These images allow comparison of the upper central and lateral incisors. Note the narrower profile of the lateral incisor and the exaggerated incisal edge asymmetry in the lateral incisor
LABIAL VIEW
PALATAL VIEW
Central Incisor
Lateral Incisor

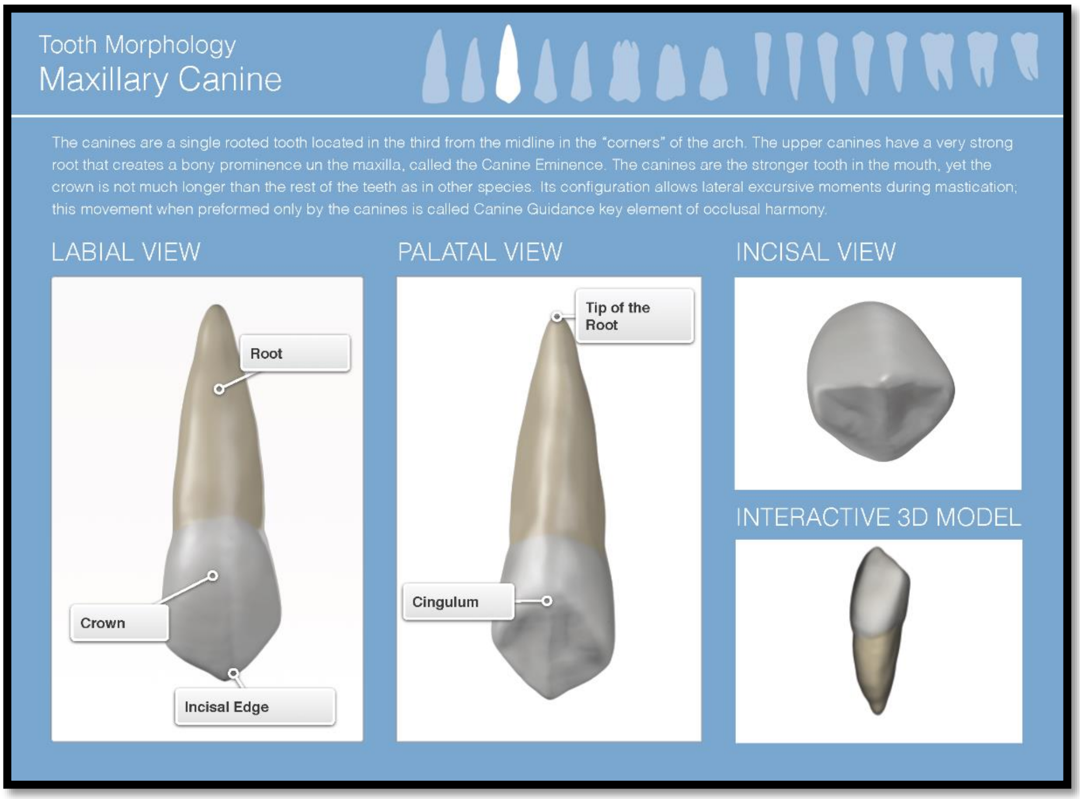

Tooth Morphology
Mandibular Central Incisor
The mandibular central incisor is the smallest tooth in the permanent dentition. It shares many features in common with the upper incisors. However, in many cases, the asymmetry of the incisal edge is less apparent.
LABIAL VIEW
Mesio-incisal Angle
Disto-incisal Angle
Single Root
Root Apex
LINGUAL VIEW
Disto-incisal Angle
Mesio-incisal Angle
Single Root
Root Apex
INCISAL VIEW
INTERACTIVE 3D MODEL

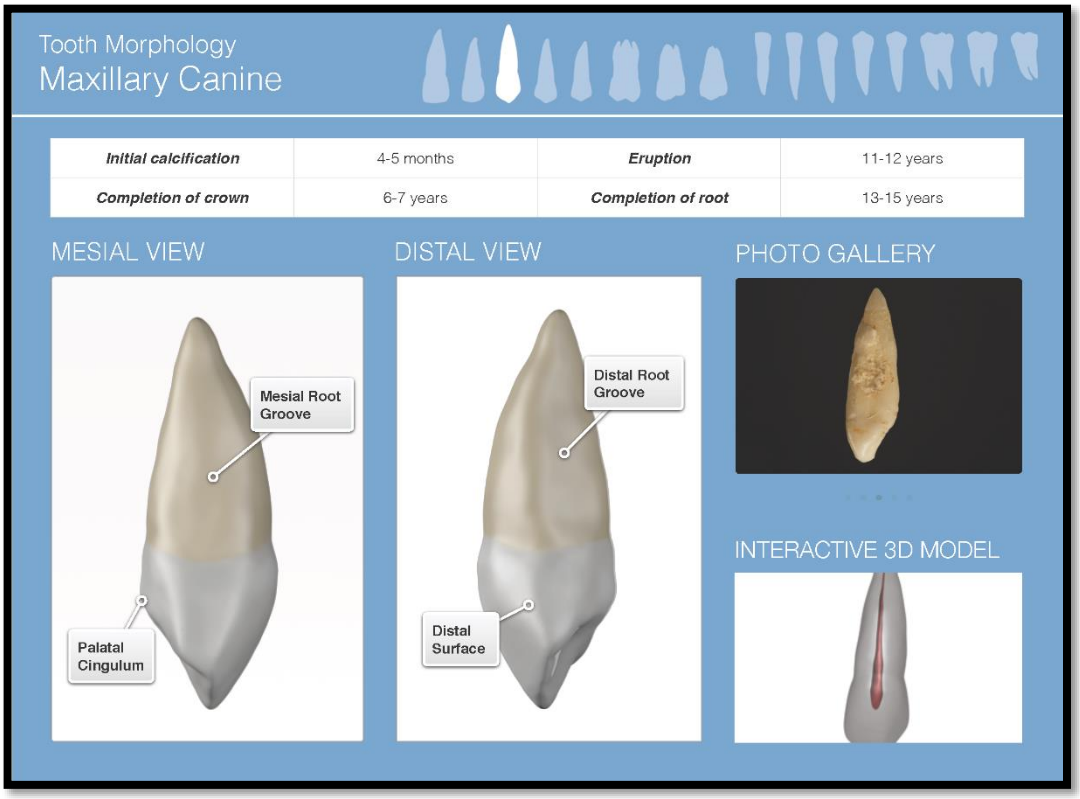

Tooth Morphology
Mandibular Central Incisor
Initial calcification
3-4 months
Eruption
6-7 years
Completion of crown
4-5 years
Completion of root
9 years
MESIAL VIEW
Lingual Cingulum
Root
DISTAL VIEW
Root
PHOTO GALLERY
INTERACTIVE 3D MODEL

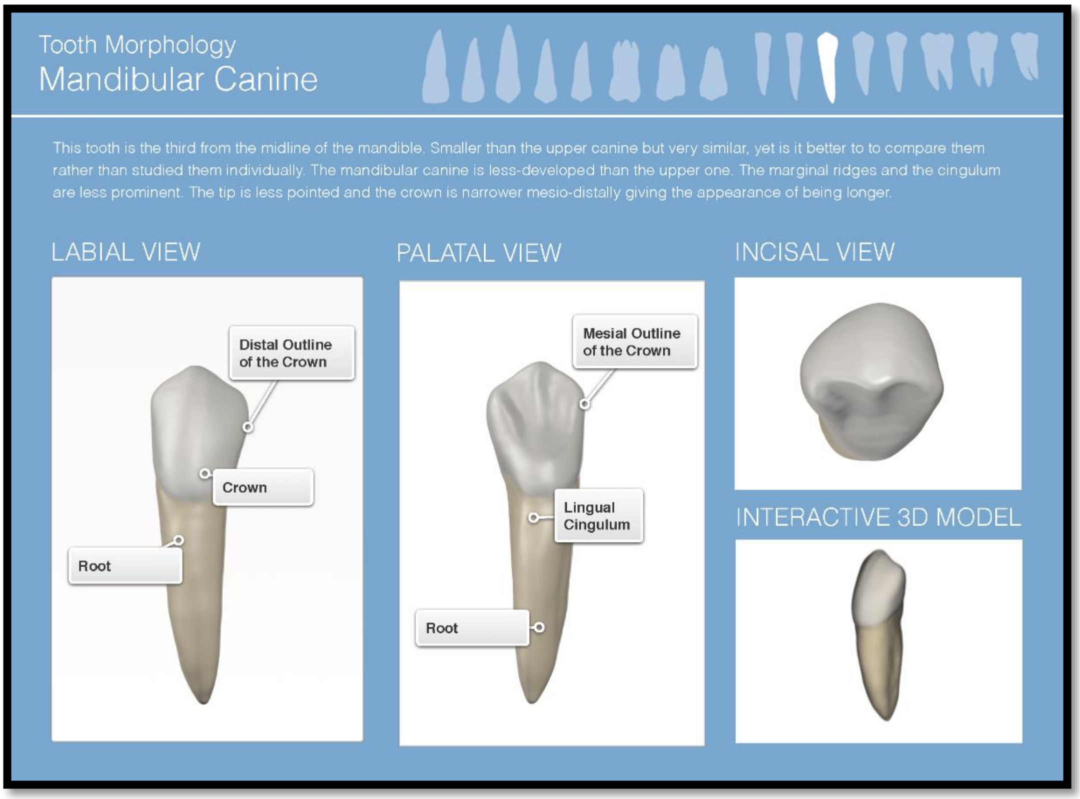

Tooth Morphology
Mandibular Lateral Incisor
This is a small tooth, though larger than the central incisor. It has a more fan shaped crown with a more marked asymmetry. The root has clear mesial and distal longitudinal groves, hinting at the presence of either 2 canals or a ribbon shaped canal system. When viewed from the incisal aspect the incisal edge appears to twist disto-lingually.
LABIAL VIEW
Mesio-incisal Angle
Distal-incisal Angle
Root
PALATAL VIEW
Disto-incisal Angle
INCISAL VIEW
INTERACTIVE 3D MODEL

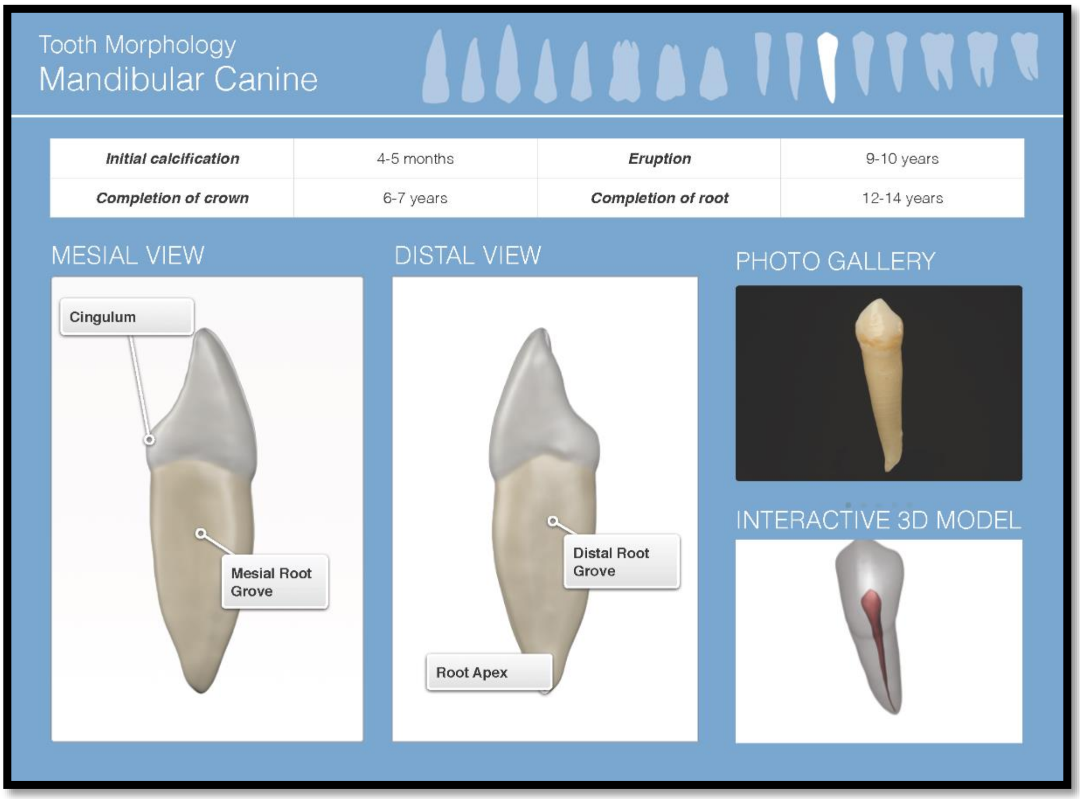

Tooth Morphology
Mandibular Lateral Incisor
Initial calcification
3-4 months
Eruption
7-8 years
Completion of crown
4-5 years
Completion of root
10 years
MESIAL VIEW
Cingulum
Mesial Root Groove
DISTAL VIEW
Distal Root Groove
Root Apex
PHOTO GALLERY
INTERACTIVE 3D MODEL


2
Tooth Morphology
Canines
The Canines main function is to tear and grip food. They are the last of the anterior teeth and are very important to guide lateral jaw movements.

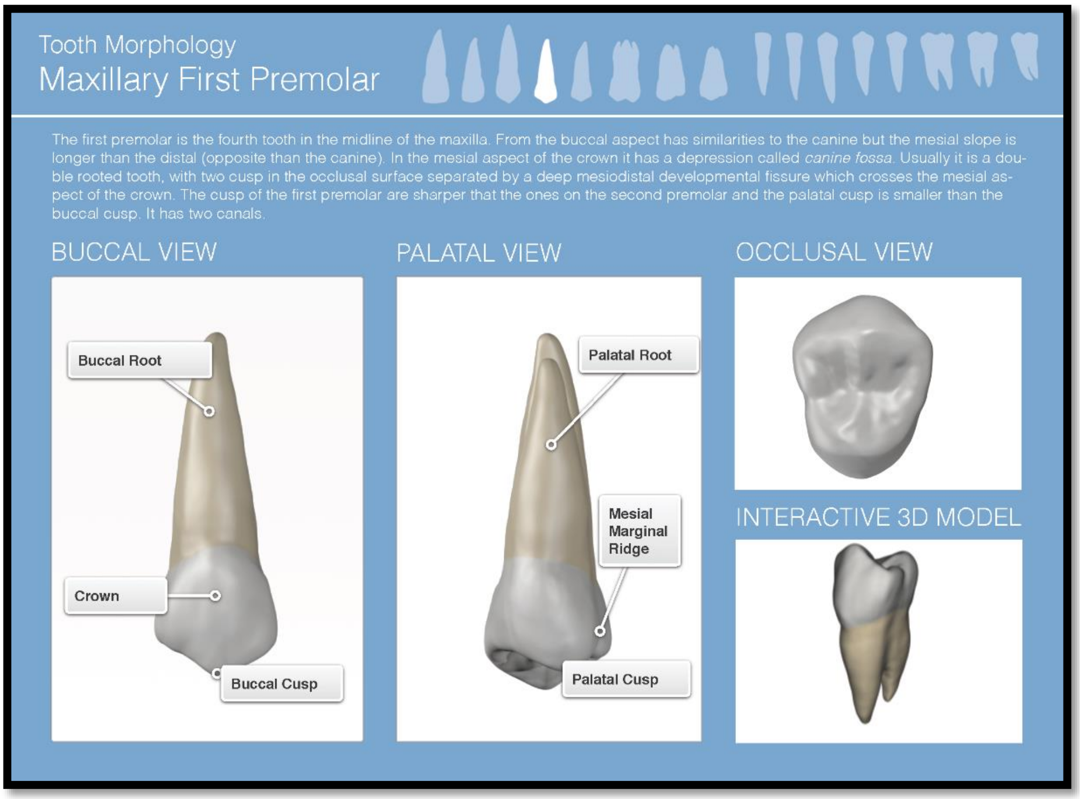

Tooth Morphology
Maxillary Canine
The canines are a single rooted tooth located in the third from the midline in the "corners" of the arch. The upper canines have a very strong root that creates a bony prominence un the maxilla, called the Canine Eminence. The canines are the stronger tooth in the mouth, yet the crown is not much longer than the rest of the teeth as in other species. Its configuration allows lateral excursive moments during mastication; this movement when preformed only by the canines is called Canine Guidance key element of occlusal harmony.
LABIAL VIEW
Root
Crown
Incisal Edge
PALATAL VIEW
Tip of the Root
Cingulum
INCISAL VIEW
INTERACTIVE 3D MODEL

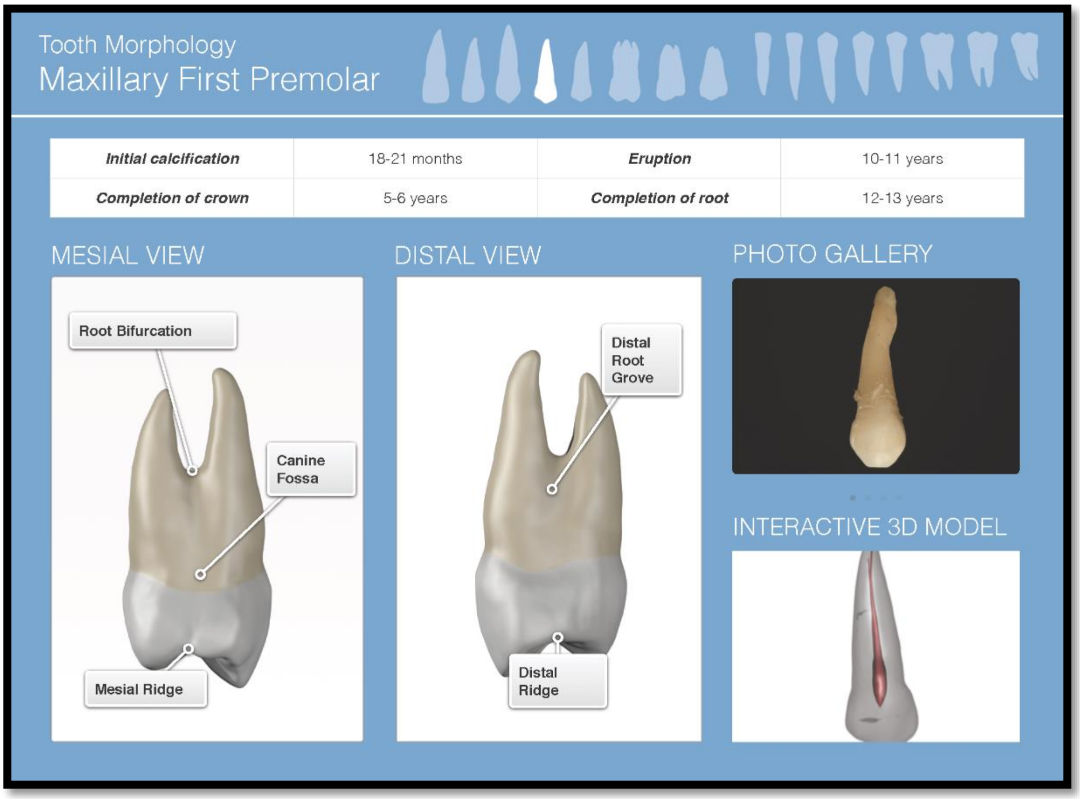

Tooth Morphology
Maxillary Canine
Initial calcification
4-5 months
Eruption
11-12 years
Completion of crown
6-7 years
Completion of root
13-15 years
MESIAL VIEW
Mesial Root Groove
Palatal Cingulum
DISTAL VIEW
Distal Root Groove
Distal Surface
PHOTO GALLERY
INTERACTIVE 3D MODEL

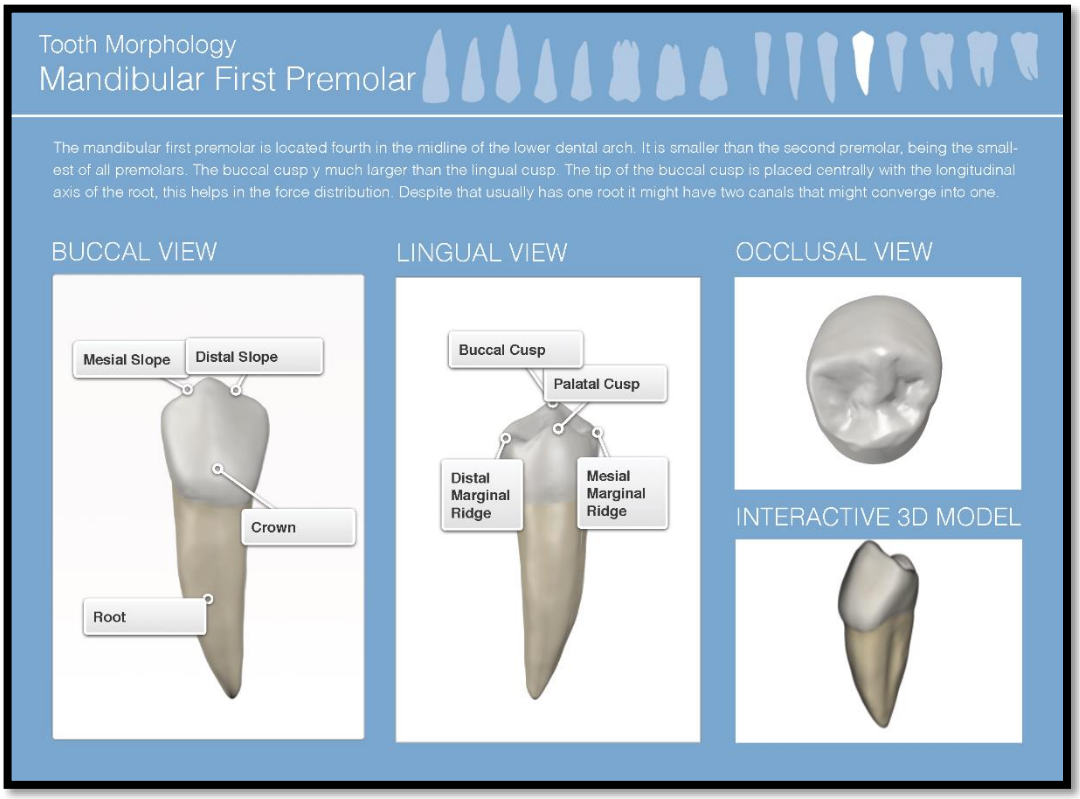

Tooth Morphology
Mandibular Canine
This tooth is the third from the midline of the mandible. Smaller than the upper canine but very similar, yet is it better to to compare them rather than studied them individually. The mandibular canine is less-developed than the upper one. The marginal ridges and the cingulum are less prominent. The tip is less pointed and the crown is narrower mesio-distally giving the appearance of being longer.
LABIAL VIEW
Distal Outline of the Crown
Crown
Root
PALATAL VIEW
Mesial Outline of the Crown
Lingual Cingulum
Root
INCISAL VIEW
INTERACTIVE 3D MODEL

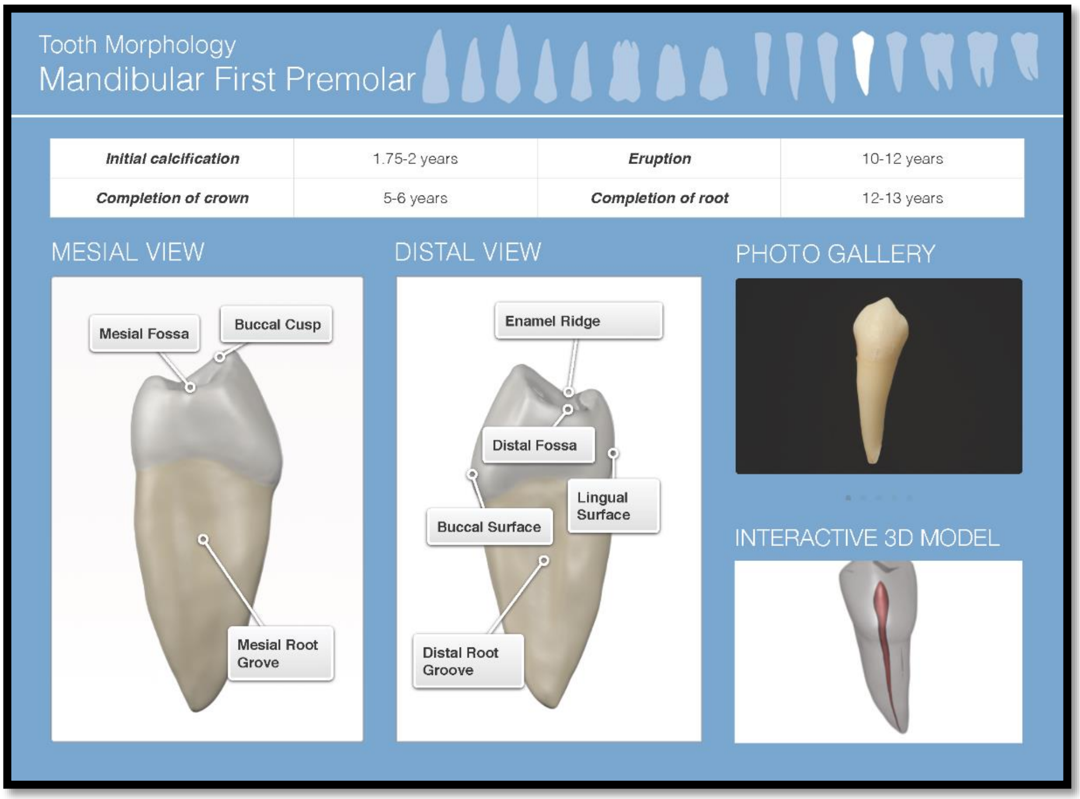

Tooth Morphology
Mandibular Canine
Initial calcification
4-5 months
Eruption
9-10 years
Completion of crown
6-7 years
Completion of root
12-14 years
MESIAL VIEW
Cingulum
Mesial Root Grove
DISTAL VIEW
Distal Root Grove
Root Apex
PHOTO GALLERY
INTERACTIVE 3D MODEL

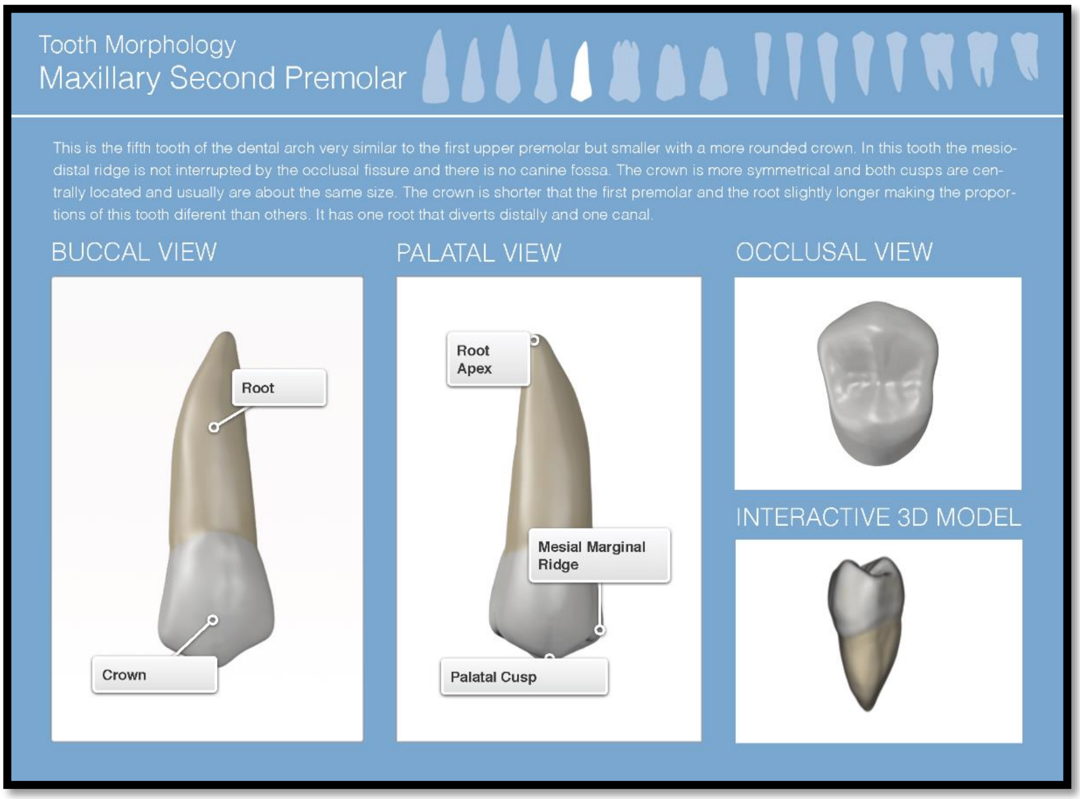

3
Tooth Morphology
Premolars
There are two premolars in the dental arch the first and second premolar. Their function is intermediate between the canines and the molars. The first premolar has mainly a tearing function but it also does crush food. Meanwhile the second premolar has mainly a food crushing function.

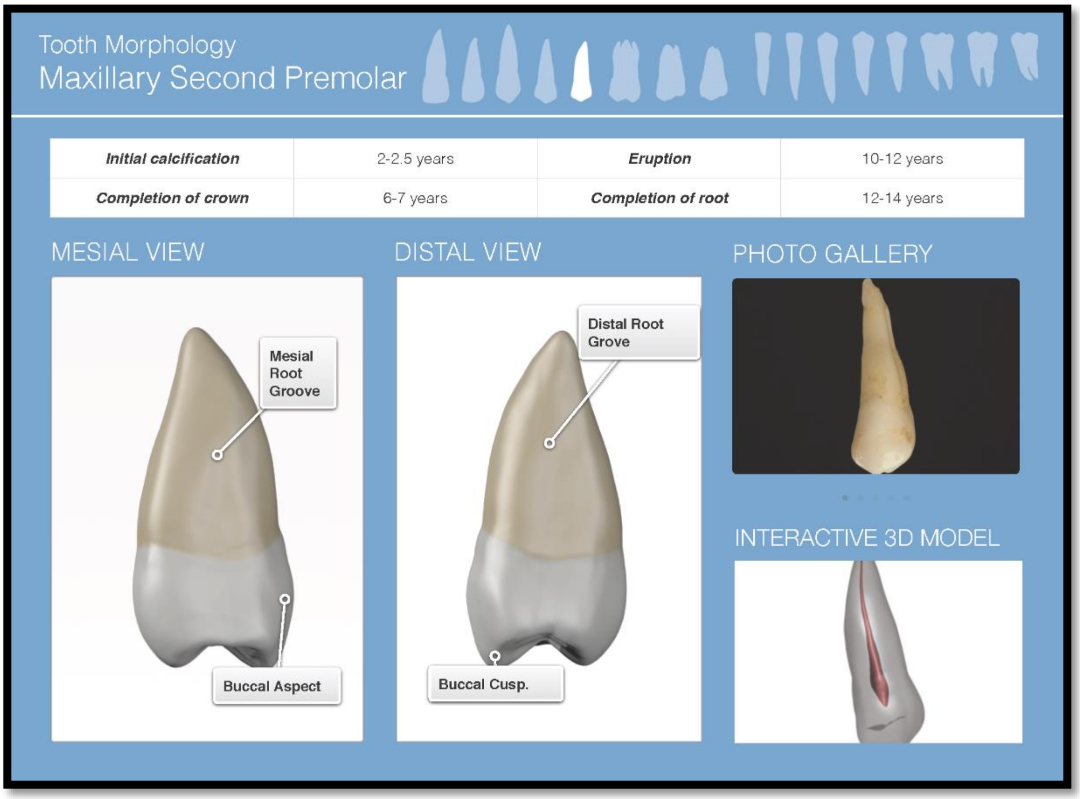

Tooth Morphology
Maxillary First Premolar
The first premolar is the fourth tooth in the midline of the maxilla. From the buccal aspect has similarities to the canine but the mesial slope is longer than the distal (opposite than the canine). In the mesial aspect of the crown it has a depression called *canine fossa*. Usually it is a double rooted tooth, with two cusp in the occlusal surface separated by a deep mesiodistal developmental fissure which crosses the mesial aspect of the crown. The cusp of the first premolar are sharper that the ones on the second premolar and the palatal cusp is smaller than the buccal cusp. It has two canals.
BUCCAL VIEW
Buccal Root
Crown
Buccal Cusp
PALATAL VIEW
Palatal Root
Mesial Marginal Ridge
Palatal Cusp
OCCLUSAL VIEW
INTERACTIVE 3D MODEL

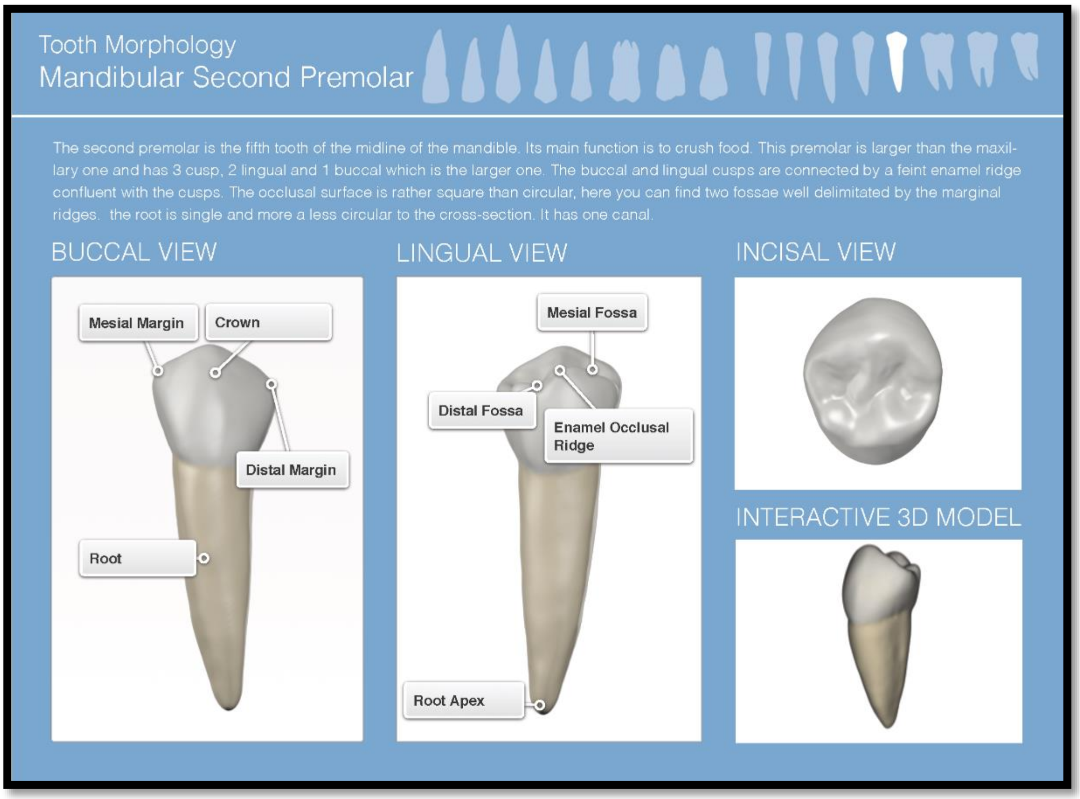

Tooth Morphology
Maxillary First Premolar
Initial calcification
18-21 months
Eruption
10-11 years
Completion of crown
5-6 years
Completion of root
12-13 years
MESIAL VIEW
Root Bifurcation
Canine Fossa
Mesial Ridge
DISTAL VIEW
Distal Root Grove
Distal Ridge
PHOTO GALLERY
INTERACTIVE 3D MODEL

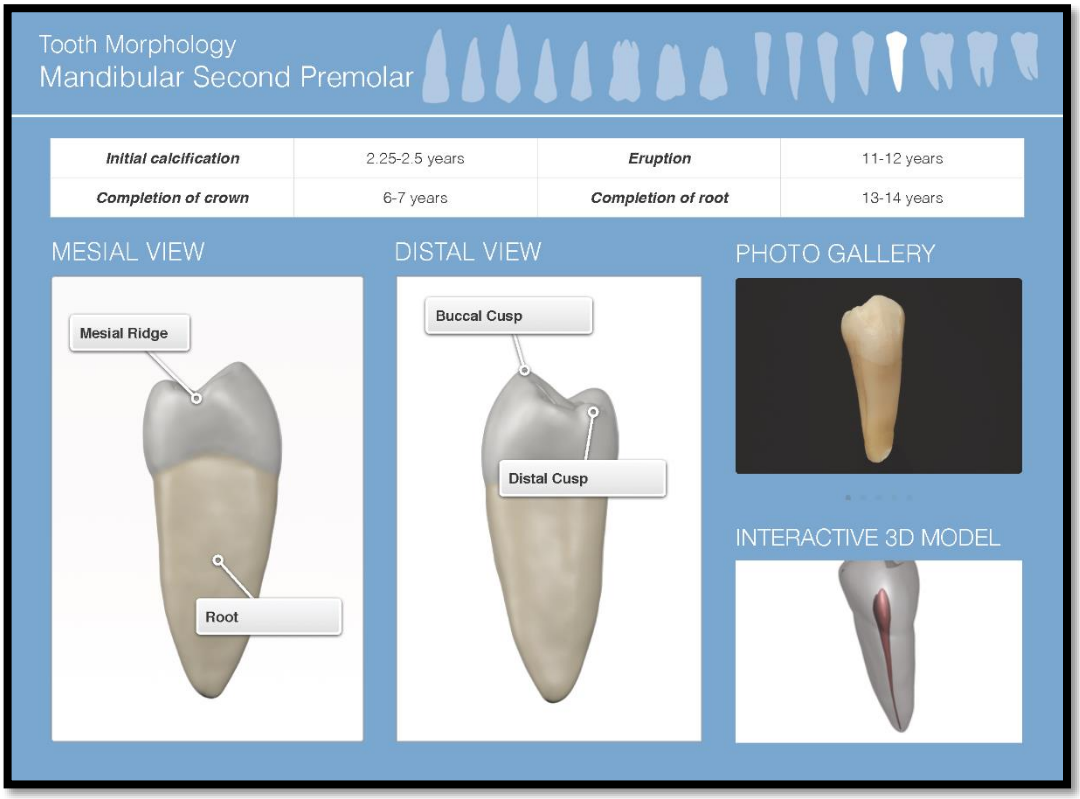

Tooth Morphology
Mandibular First Premolar
The mandibular first premolar is located fourth in the midline of the lower dental arch. It is smaller than the second premolar, being the small-est of all premolars. The buccal cusp y much larger than the lingual cusp. The tip of the buccal cusp is placed centrally with the longitudinal axis of the root, this helps in the force distribution. Despite that usually has one root it might have two canals that might converge into one.
BUCCAL VIEW
Mesial Slope
Distal Slope
Crown
Root
LINGUAL VIEW
Buccal Cusp
Palatal Cusp
Distal Marginal Ridge
Mesial Marginal Ridge
OCCLUSAL VIEW
INTERACTIVE 3D MODEL


Tooth Morphology
Mandibular First Premolar
Initial calcification
1.75-2 years
Eruption
10-12 years
Completion of crown
5-6 years
Completion of root
12-13 years
MESIAL VIEW
Mesial Fossa
Buccal Cusp
Mesial Root Grove
DISTAL VIEW
Enamel Ridge
Distal Fossa
Lingual Surface
Buccal Surface
Distal Root Groove
PHOTO GALLERY
INTERACTIVE 3D MODEL

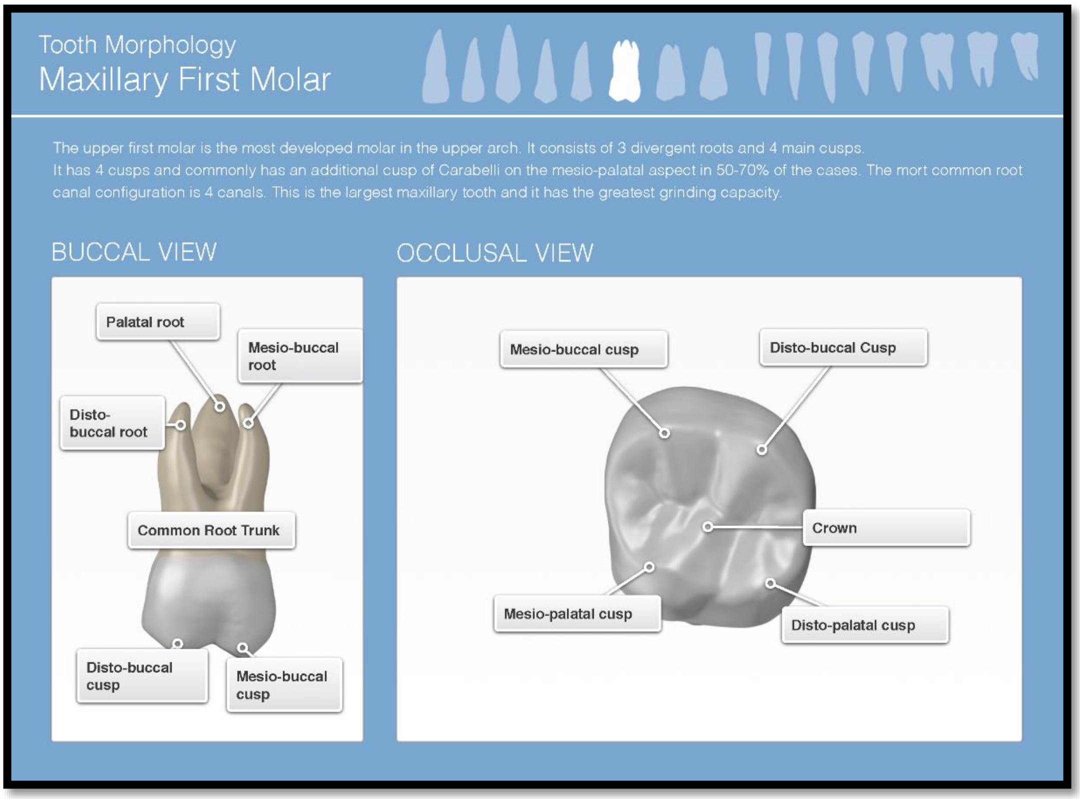

Tooth Morphology
Maxillary Second Premolar
This is the fifth tooth of the dental arch very similar to the first upper premolar but smaller with a more rounded crown. In this tooth the mesio-distal ridge is not interrupted by the occlusal fissure and there is no canine fossa. The crown is more symmetrical and both cusps are centrally located and usually are about the same size. The crown is shorter that the first premolar and the root slightly longer making the proportions of this tooth diferent than others. It has one root that diverts distally and one canal.
BUCCAL VIEW
Root
Crown
PALATAL VIEW
Root Apex
Mesial Marginal Ridge
Palatal Cusp
OCCLUSAL VIEW
INTERACTIVE 3D MODEL

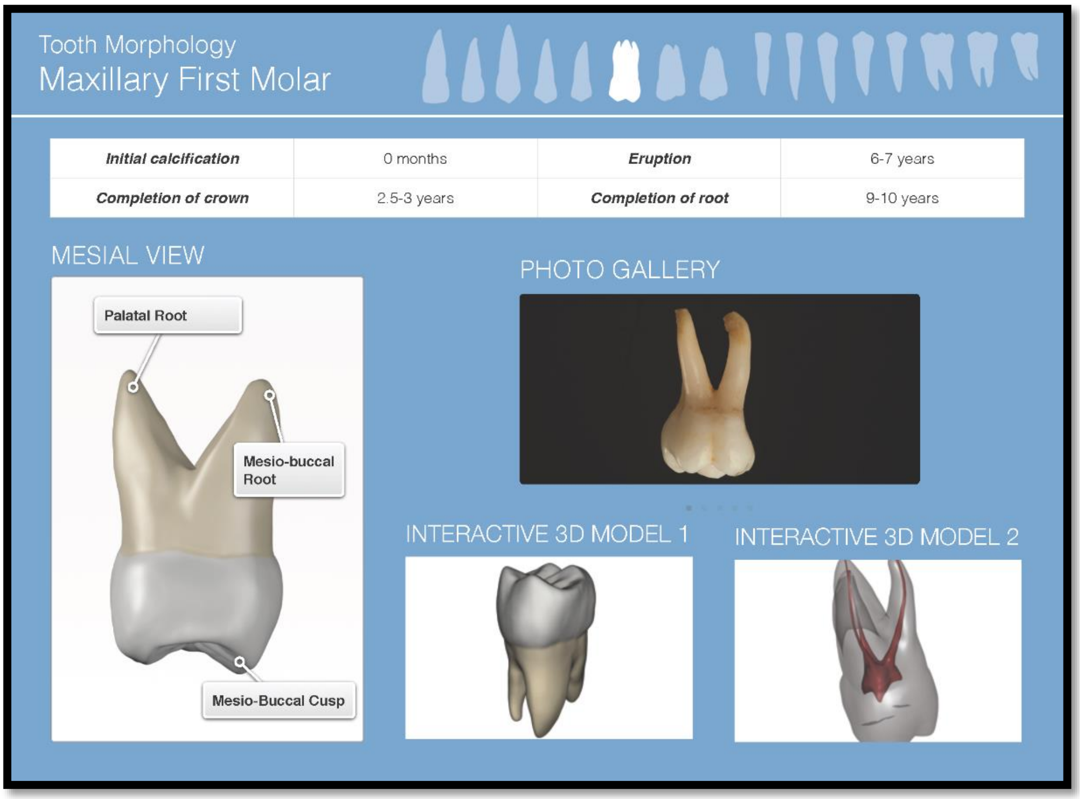

Tooth Morphology
Maxillary Second Premolar
Initial calcification
2-2.5 years
Eruption
10-12 years
Completion of crown
6-7 years
Completion of root
12-14 years
MESIAL VIEW
Mesial Root Groove
Buccal Aspect
DISTAL VIEW
Distal Root Grove
Buccal Cusp.
PHOTO GALLERY
INTERACTIVE 3D MODEL

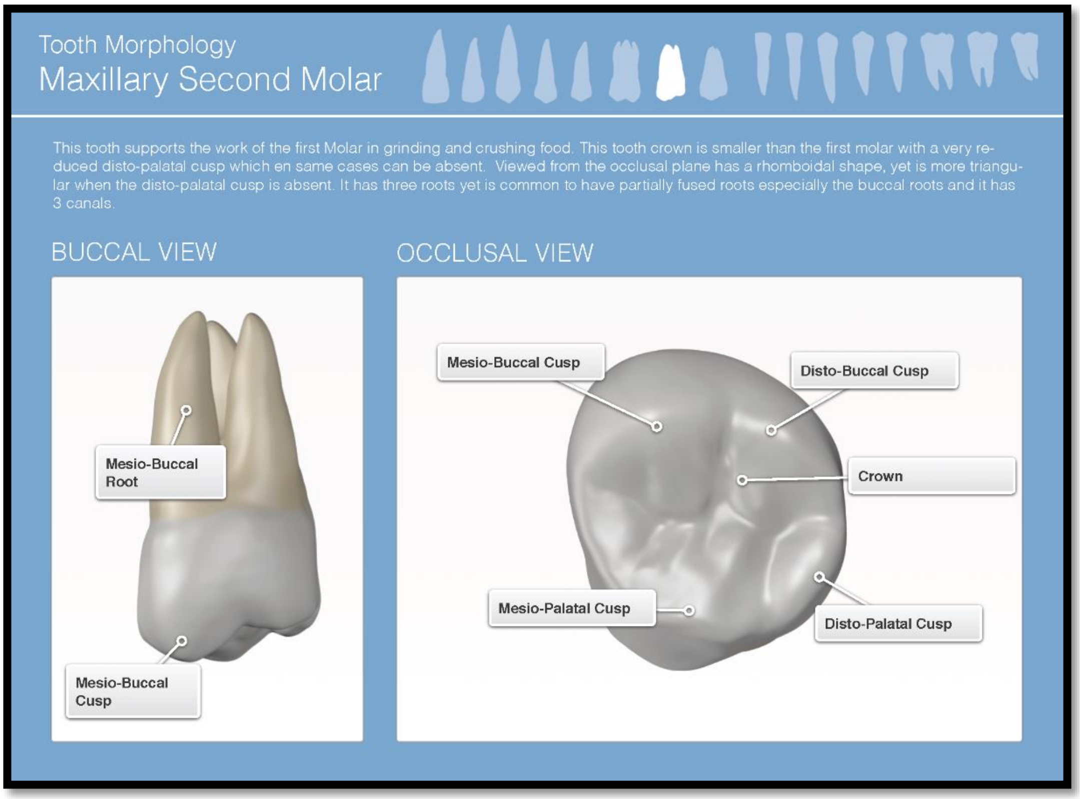

Tooth Morphology
Mandibular Second Premolar
The second premolar is the fifth tooth of the midline of the mandible. Its main function is to crush food. This premolar is larger than the maxillary one and has 3 cusp, 2 lingual and 1 buccal which is the larger one. The buccal and lingual cusps are connected by a feint enamel ridge confluent with the cusps. The occlusal surface is rather square than circular, here you can find two fossae well delimitated by the marginal ridges. the root is single and more a less circular to the cross-section. It has one canal.
BUCCAL VIEW
Mesial Margin
Crown
Distal Margin
Root
LINGUAL VIEW
Mesial Fossa
Distal Fossa
Enamel Occlusal Ridge
Root Apex
INCISAL VIEW
INTERACTIVE 3D MODEL

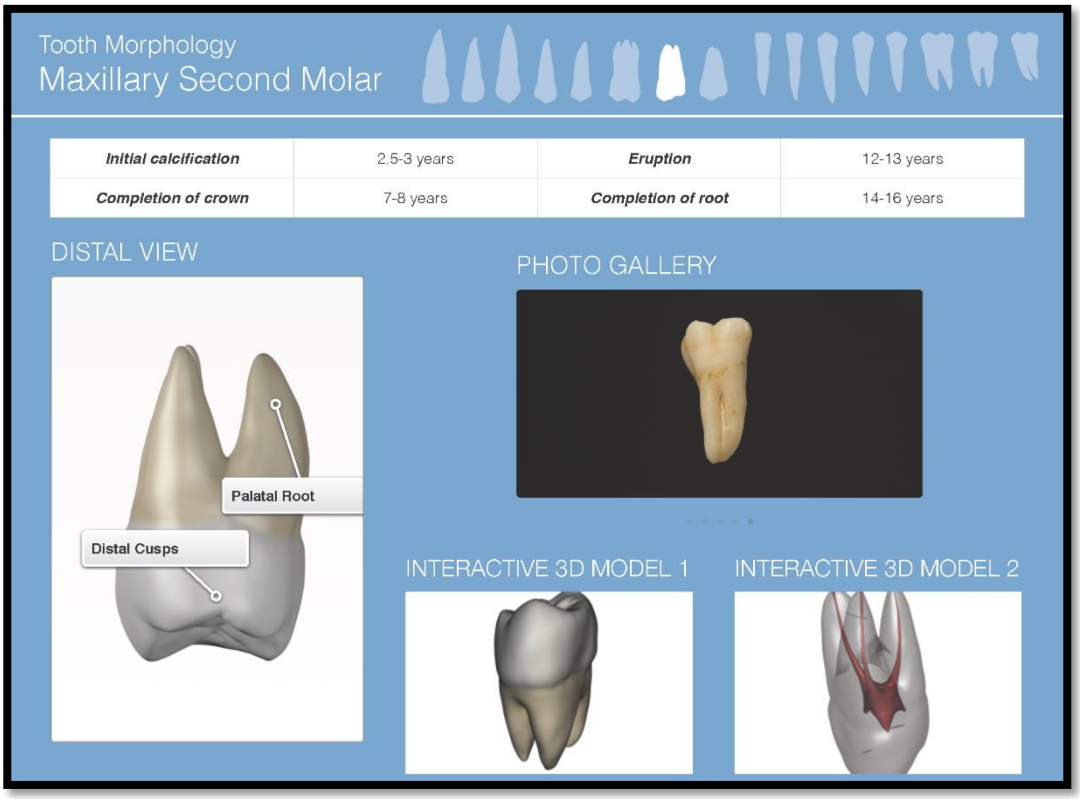

Tooth Morphology
Mandibular Second Premolar
Initial calcification
2.25-2.5 years
Eruption
11-12 years
Completion of crown
6-7 years
Completion of root
13-14 years
MESIAL VIEW
Mesial Ridge
Root
DISTAL VIEW
Buccal Cusp
Distal Cusp
PHOTO GALLERY
INTERACTIVE 3D MODEL

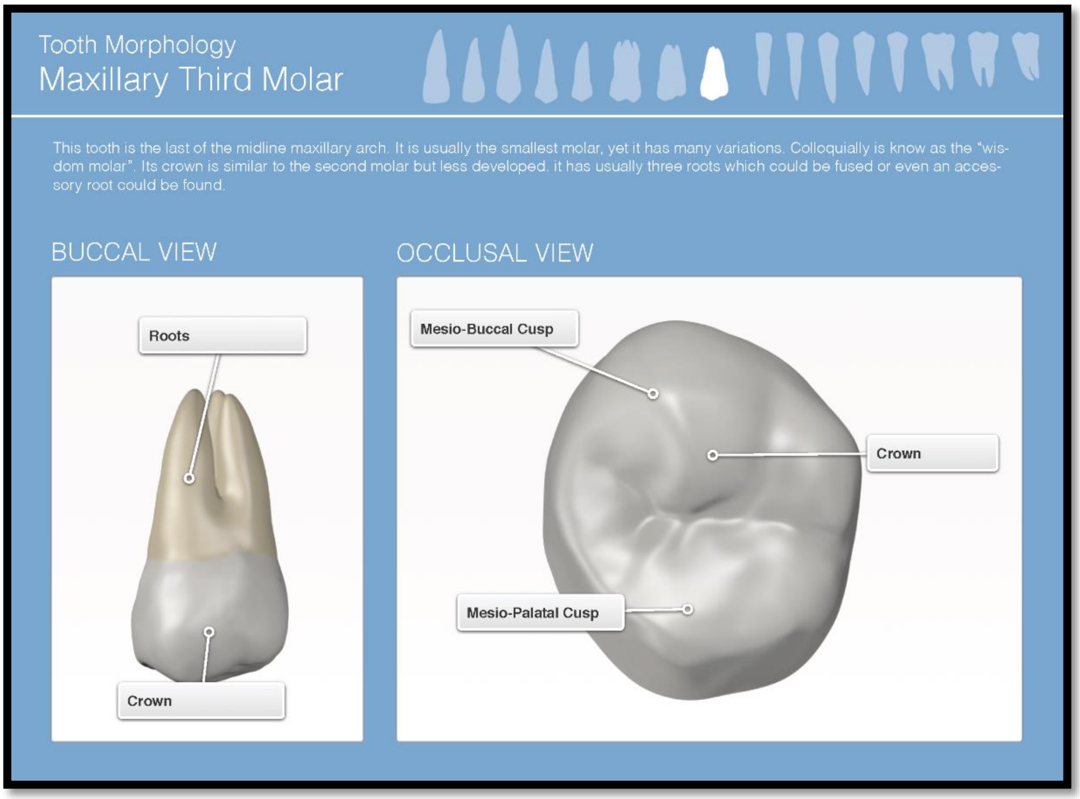

4
Tooth Morphology
Molars
These are the most posterior tooth of the mouth. There are three of them per side of the arch and they have the biggest occlusal surface. Their main function is to crush food.

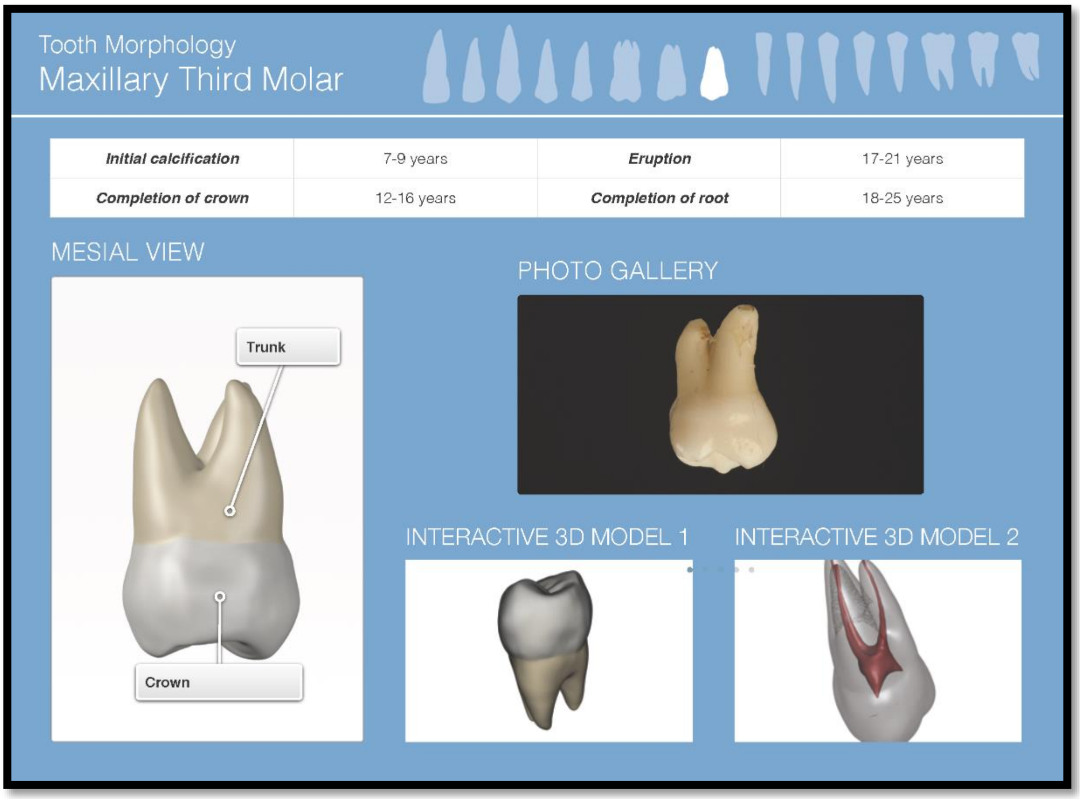

Tooth Morphology
Maxillary First Molar
The upper first molar is the most developed molar in the upper arch. It consists of 3 divergent roots and 4 main cusps.
It has 4 cusps and commonly has an additional cusp of Carabelli on the mesio-palatal aspect in 50-70% of the cases. The mort common root canal configuration is 4 canals. This is the largest maxillary tooth and it has the greatest grinding capacity.
BUCCAL VIEW
Palatal root
Mesio-buccal root
Disto-buccal root
Common Root Trunk
Disto-buccal cusp
Mesio-buccal cusp
OCCLUSAL VIEW
Mesio-buccal cusp
Disto-buccal Cusp
Crown
Mesio-palatal cusp
Disto-palatal cusp


Tooth Morphology
Maxillary First Molar
Initial calcification
0 months
Eruption
6-7 years
Completion of crown
2.5-3 years
Completion of root
9-10 years
MESIAL VIEW
Palatal Root
Mesio-buccal Root
Mesio-Buccal Cusp
PHOTO GALLERY
INTERACTIVE 3D MODEL 1
INTERACTIVE 3D MODEL 2


Tooth Morphology
Maxillary Second Molar
This tooth supports the work of the first Molar in grinding and crushing food. This tooth crown is smaller than the first molar with a very reduced disto-palatal cusp which en same cases can be absent. Viewed from the occlusal plane has a rhomboidal shape, yet is more triangular when the disto-palatal cusp is absent. It has three roots yet is common to have partially fused roots especially the buccal roots and it has 3 canals.
BUCCAL VIEW
Mesio-Buccal Root
Mesio-Buccal Cusp
OCCLUSAL VIEW
Mesio-Buccal Cusp
Disto-Buccal Cusp
Crown
Mesio-Palatal Cusp
Disto-Palatal Cusp


Tooth Morphology
Maxillary Second Molar
Initial calcification
2.5-3 years
Eruption
12-13 years
Completion of crown
7-8 years
Completion of root
14-16 years
DISTAL VIEW
Palatal Root
Distal Cusps
PHOTO GALLERY
INTERACTIVE 3D MODEL 1
INTERACTIVE 3D MODEL 2


Tooth Morphology
Maxillary Third Molar
This tooth is the last of the midline maxillary arch. It is usually the smallest molar, yet it has many variations. Colloquially is know as the "wisdom molar". Its crown is similar to the second molar but less developed. it has usually three roots which could be fused or even an accessory root could be found.
BUCCAL VIEW
Roots
Crown
OCCLUSAL VIEW
Mesio-Buccal Cusp
Crown
Mesio-Palatal Cusp

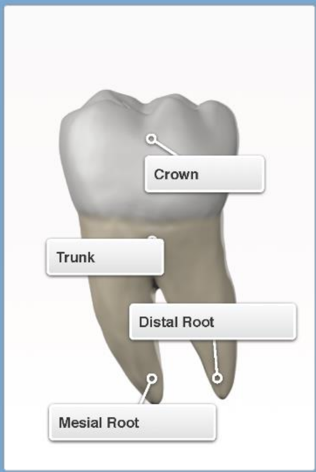

Tooth Morphology
Maxillary Third Molar
Initial calcification
7-9 years
Eruption
17-21 years
Completion of crown
12-16 years
Completion of root
18-25 years
MESIAL VIEW
Trunk
Crown
PHOTO GALLERY
INTERACTIVE 3D MODEL 1
INTERACTIVE 3D MODEL 2

Tooth Morphology

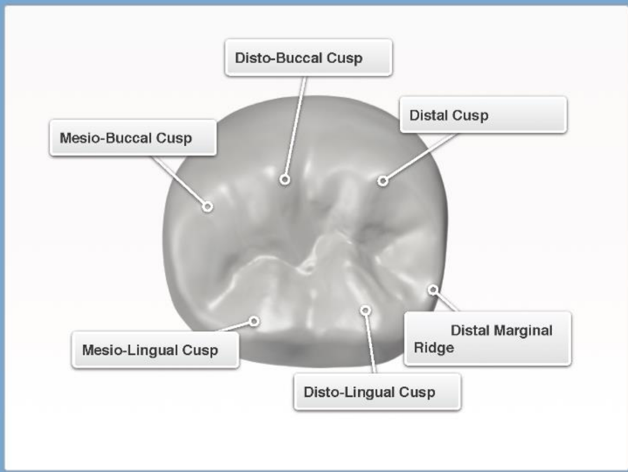
Mandibular First Molar

This molar has 5 cusps, 3 in the buccal side and 2 lingually. From the buccal aspect the 5 cusps are visible, this can help in the identification of this molar. It has two roots and 3 canals, two of which are inside the mesial root that has a flattened shaped. The distal root is more rounded and booth root diverts distally. In the occlusal surface usually its has a Y shape formed by the lingual and the two buccal fissures. This is the larges Mandibular tooth.

BUCCAL VIEW



OCCLUSAL VIEW



Tooth Morphology
Mandibular First Molar

Initial calcification	0 months	***Eruption***	6-7 years
Completion of crown	2.5-3 years	***Completion of root***	9-10 years

MESIAL VIEW

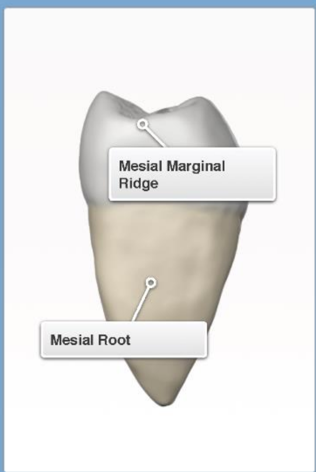
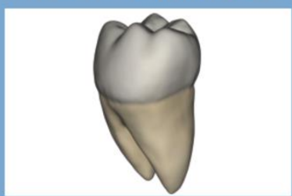


PHOTO GALLERY

INTERACTIVE 3D MODEL 1



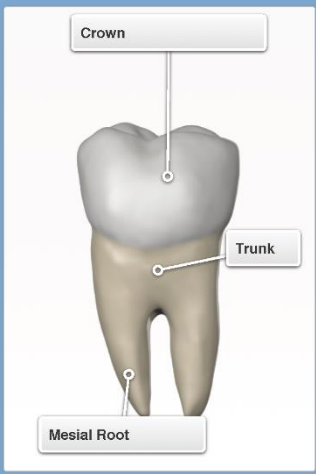
INTERACTIVE 3D MODEL 2

Tooth Morphology

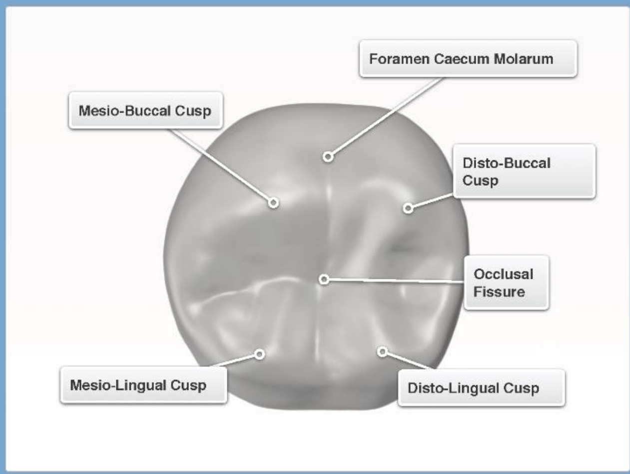
Mandibular Second Molar

This is the seventh tooth from the midline of the mandibular arch. It is similar molar than the first mandibular molar, but this one has 4 cusp rather than 5. All the 4 cusp are very symmetrical and are divided by a cruciform fissure. It has two roots and three canals, 2 mesial and 1 distal. Its occlusal shape is usually rounded square

BUCCAL VIEW



OCCLUSAL VIEW



Tooth Morphology

Mandibular Second Molar

Initial calcification	2.5 years	***Eruption***	11-13 years
Completion of crown	7-8 years	***Completion of root***	14-15 years

MESIAL VIEW

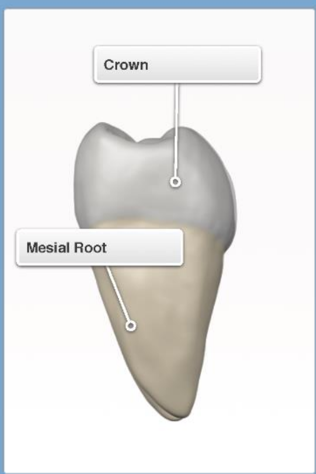
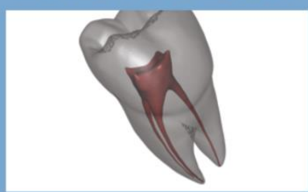
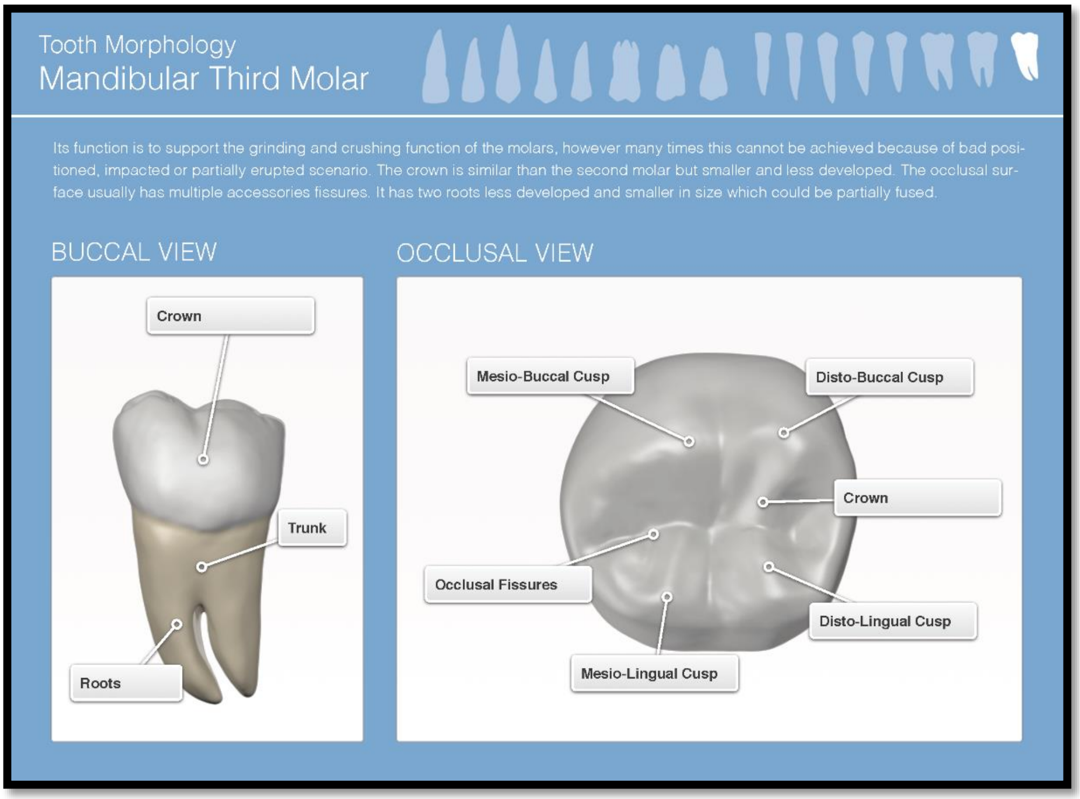


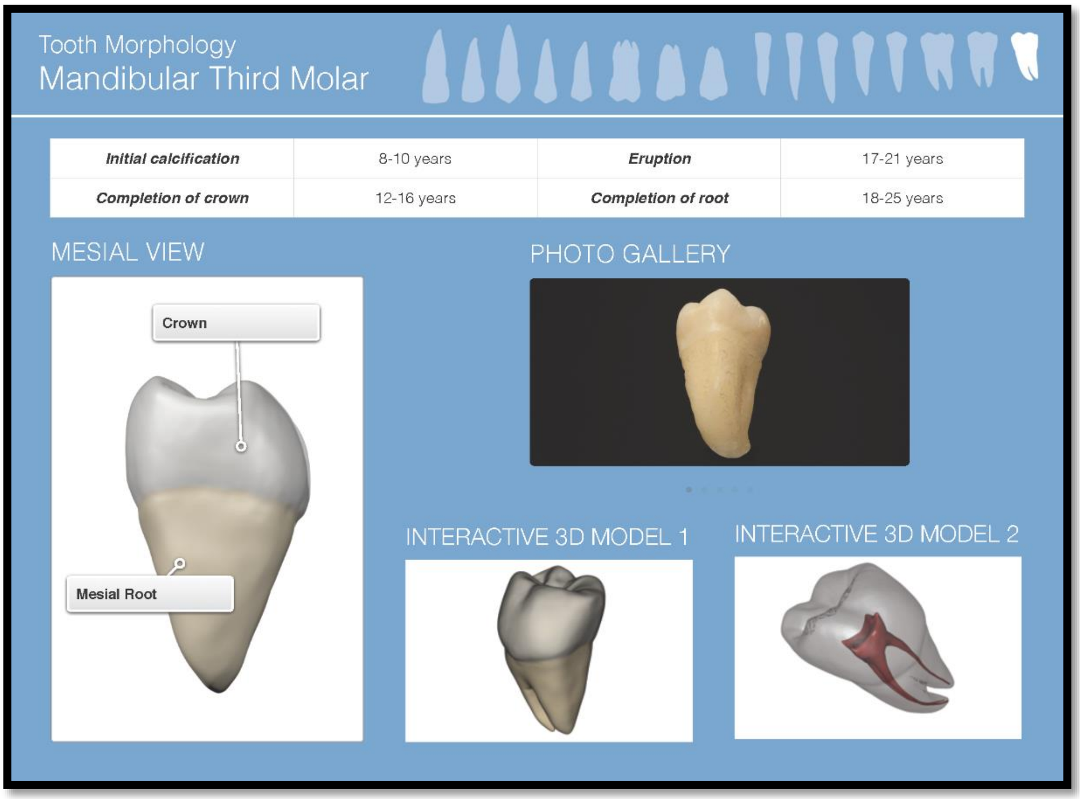
PHOTO GALLERY

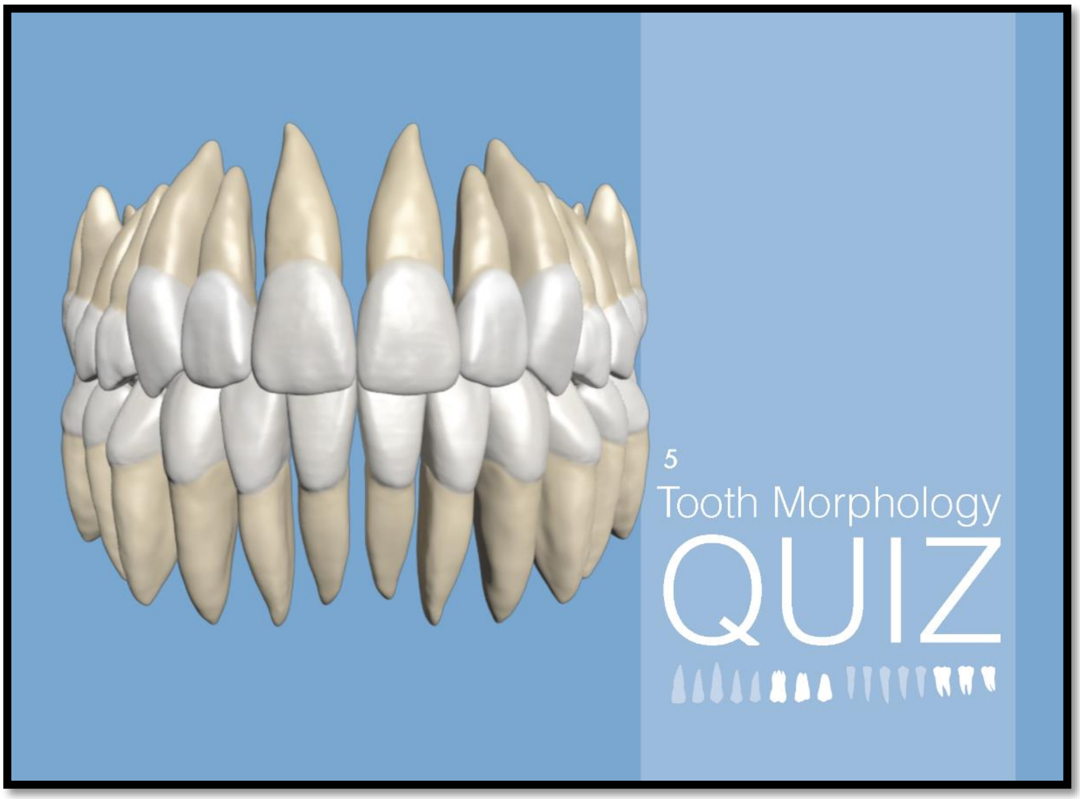
INTERACTIVE 3D MODEL 1

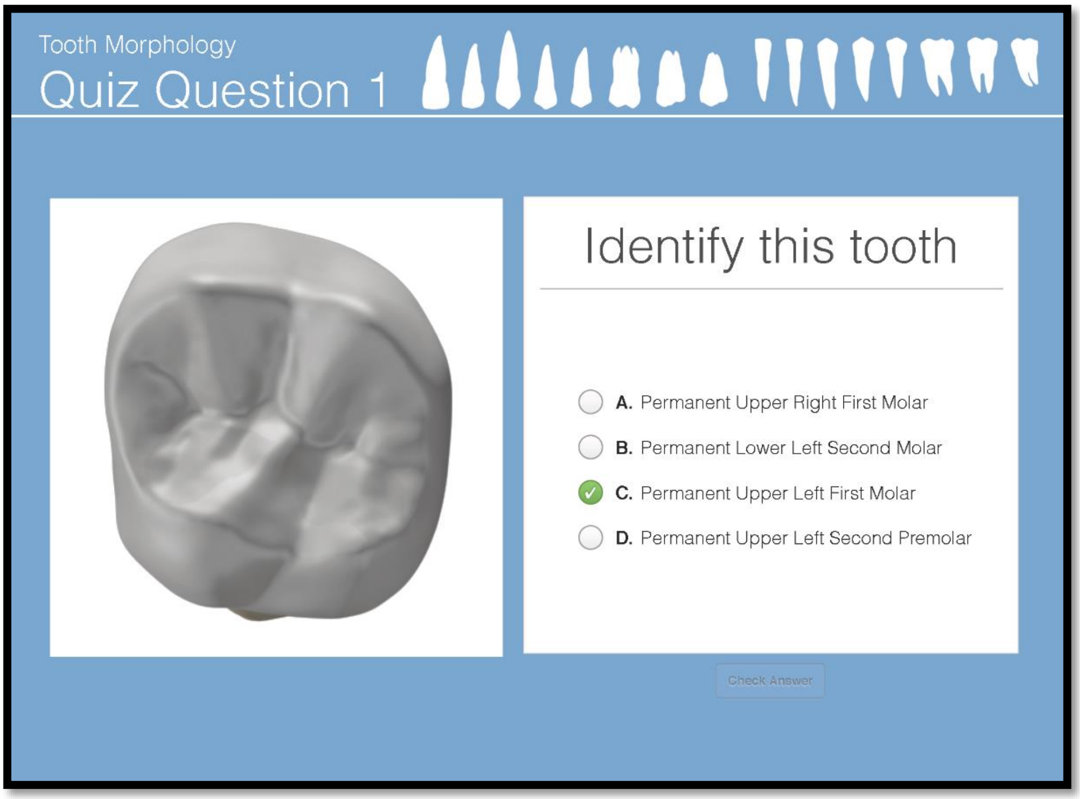
INTERACTIVE 3D MODEL 2

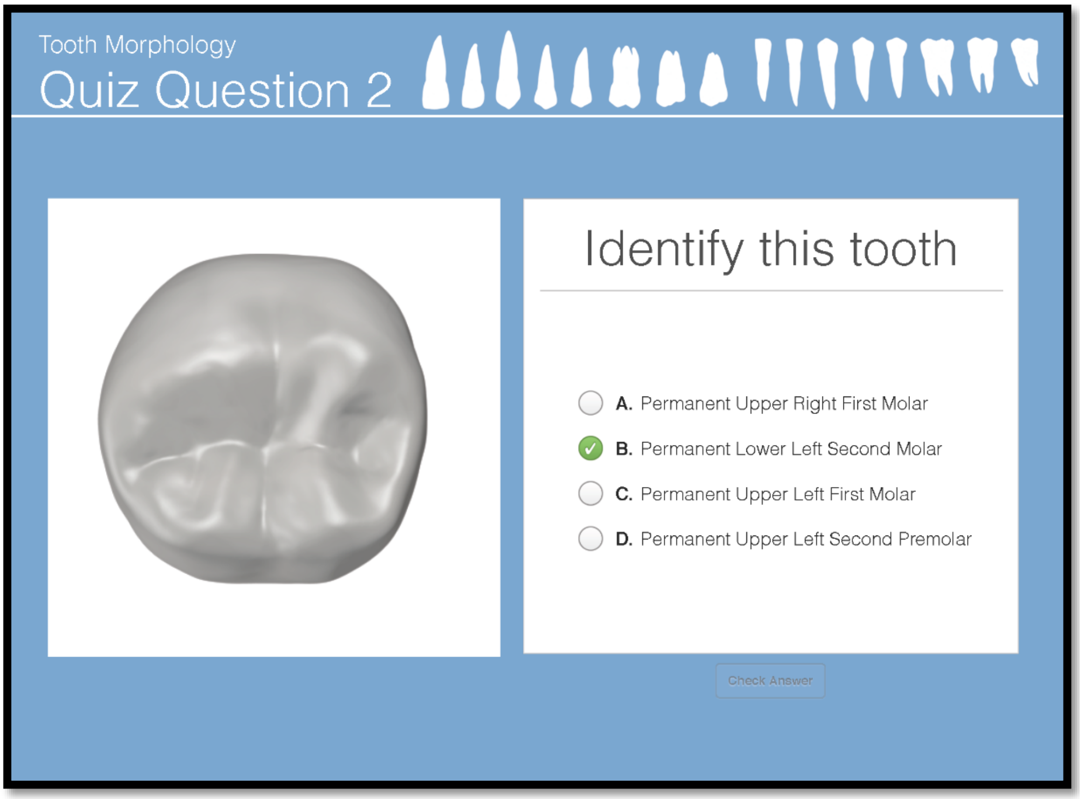


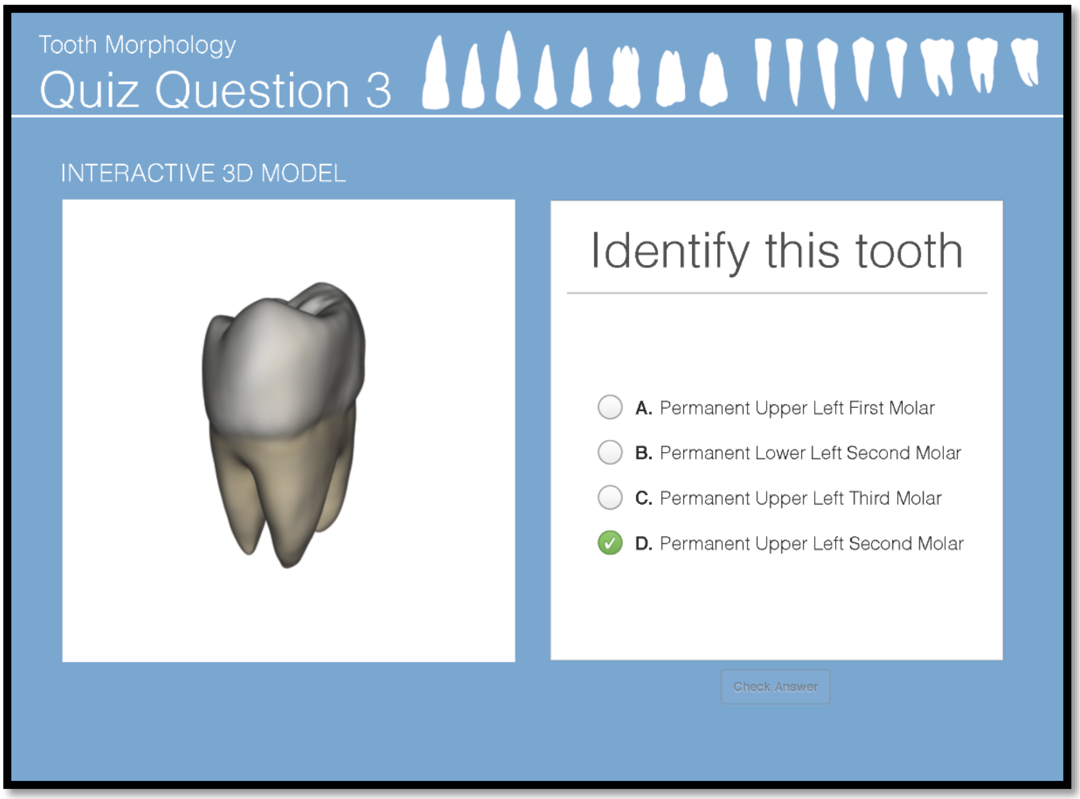

Tooth Morphology
Mandibular Third Molar
Its function is to support the grinding and crushing function of the molars, however many times this cannot be achieved because of bad positioned, impacted or partially erupted scenario. The crown is similar than the second molar but smaller and less developed. The occlusal surface usually has multiple accessories fissures. It has two roots less developed and smaller in size which could be partially fused.
BUCCAL VIEW
Crown
Trunk
Roots
OCCLUSAL VIEW
Mesio-Buccal Cusp
Disto-Buccal Cusp
Crown
Occlusal Fissures
Disto-Lingual Cusp
Mesio-Lingual Cusp

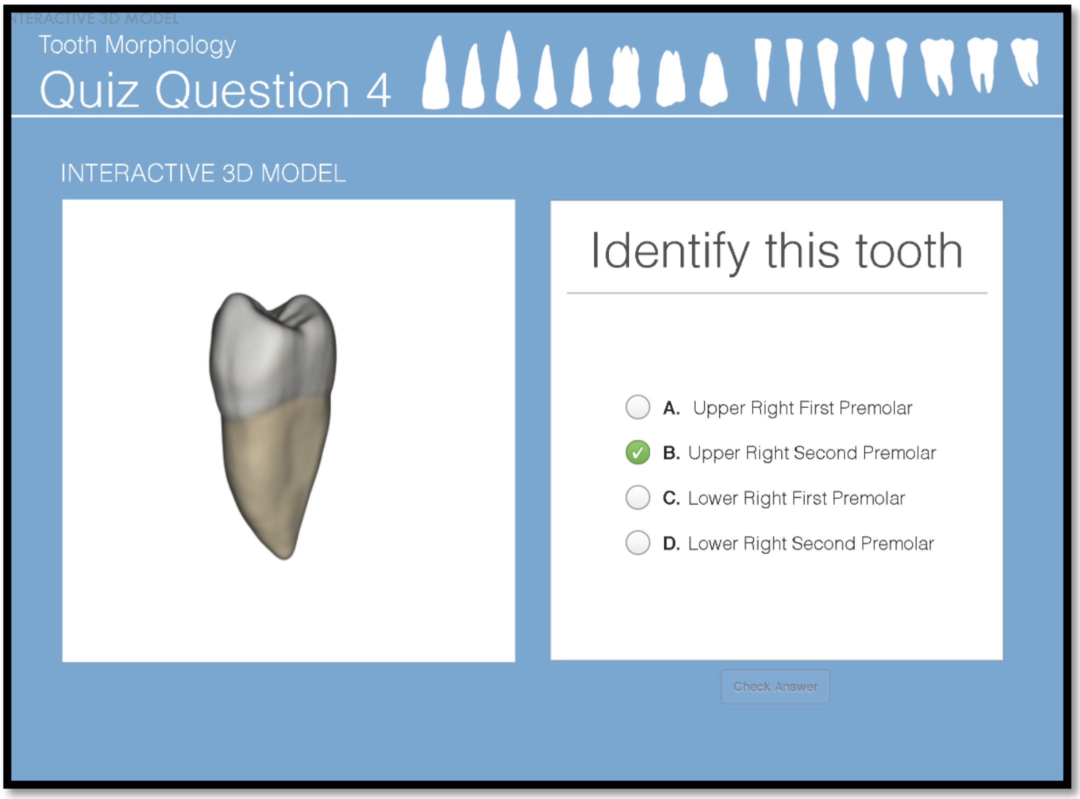

Tooth Morphology
Mandibular Third Molar
Initial calcification
8-10 years
Eruption
17-21 years
Completion of crown
12-16 years
Completion of root
18-25 years
MESIAL VIEW
Crown
Mesial Root
PHOTO GALLERY
INTERACTIVE 3D MODEL 1
INTERACTIVE 3D MODEL 2

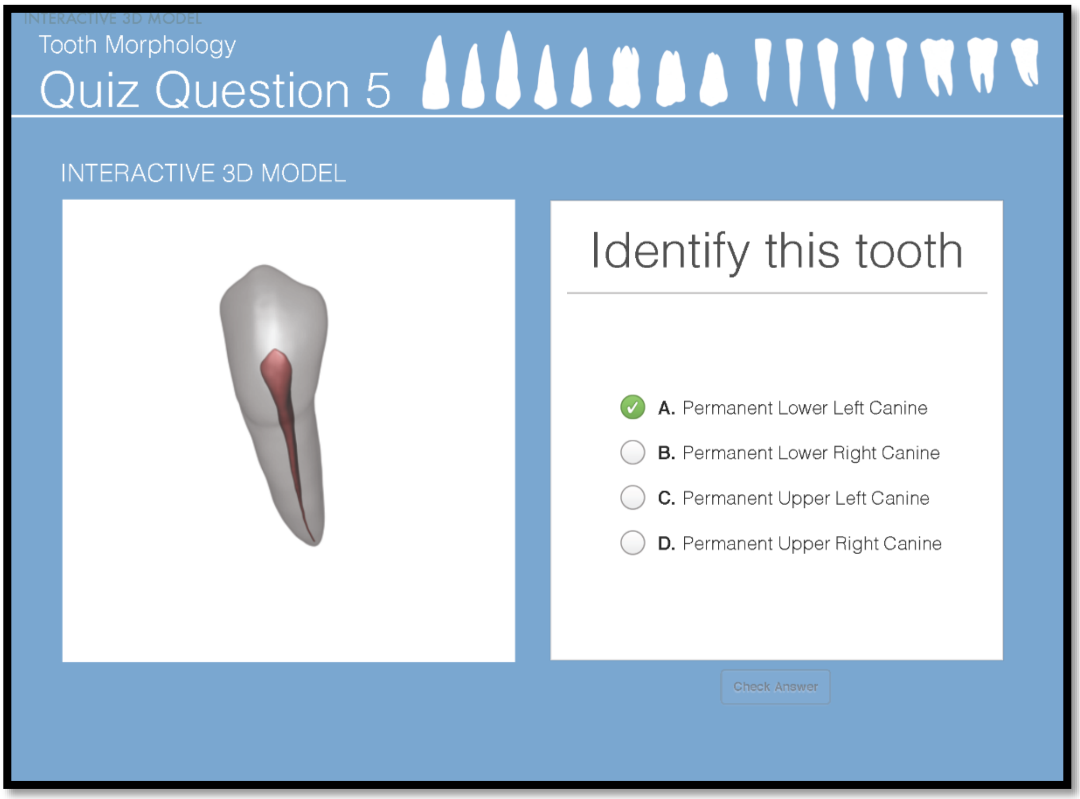

5
Tooth Morphology
QUIZ

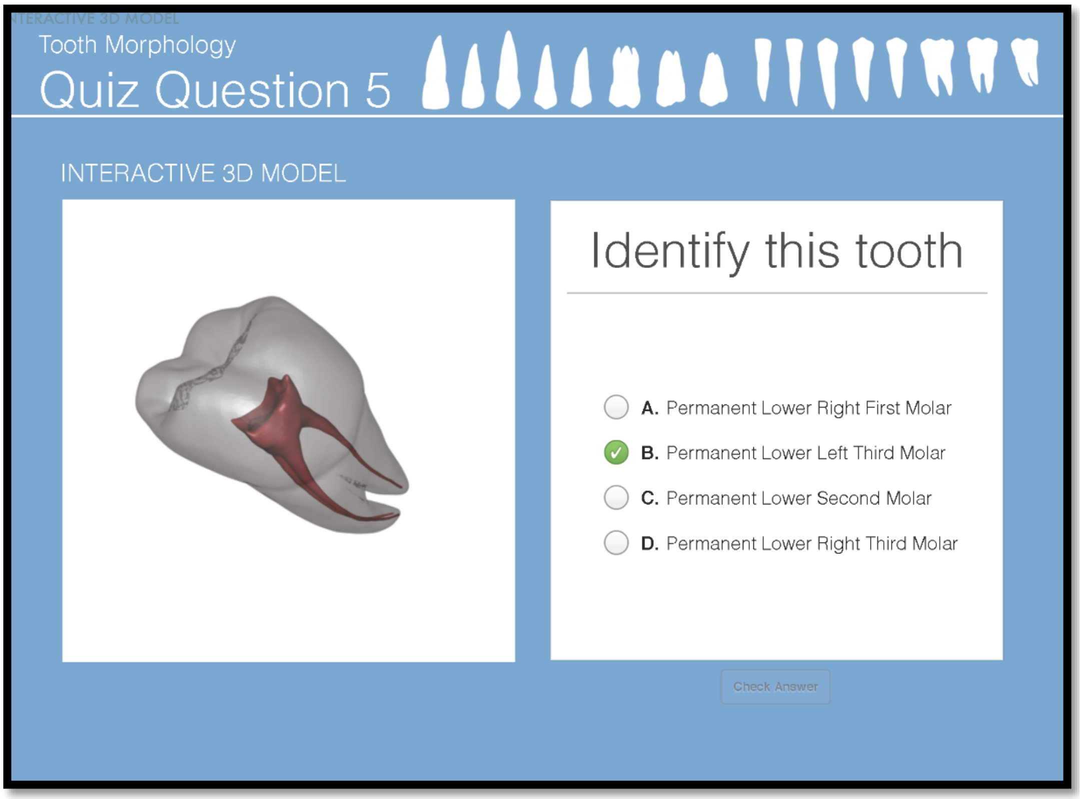

Tooth Morphology
Quiz Question 1
Identify this tooth
A. Permanent Upper Right First Molar
B. Permanent Lower Left Second Molar
C. Permanent Upper Left First Molar
D. Permanent Upper Left Second Premolar
Check Answer

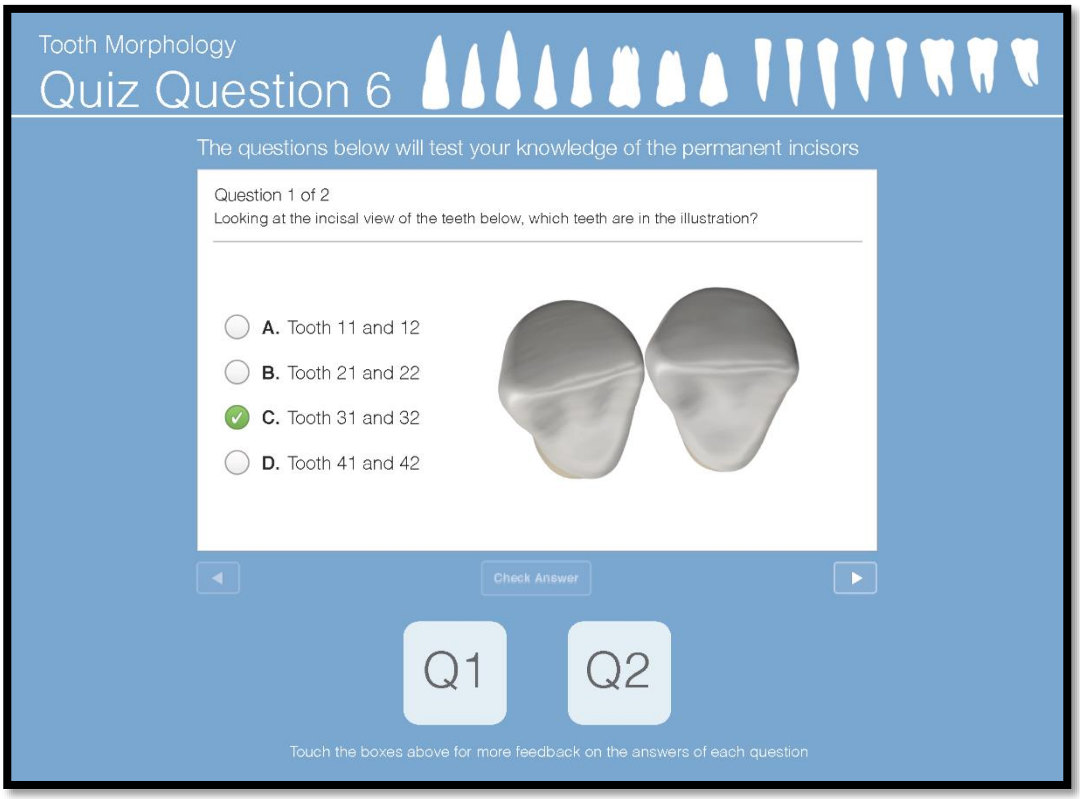

Tooth Morphology
Quiz Question 2
Identify this tooth
A. Permanent Upper Right First Molar
B. Permanent Lower Left Second Molar
C. Permanent Upper Left First Molar
D. Permanent Upper Left Second Premolar
Check Answer

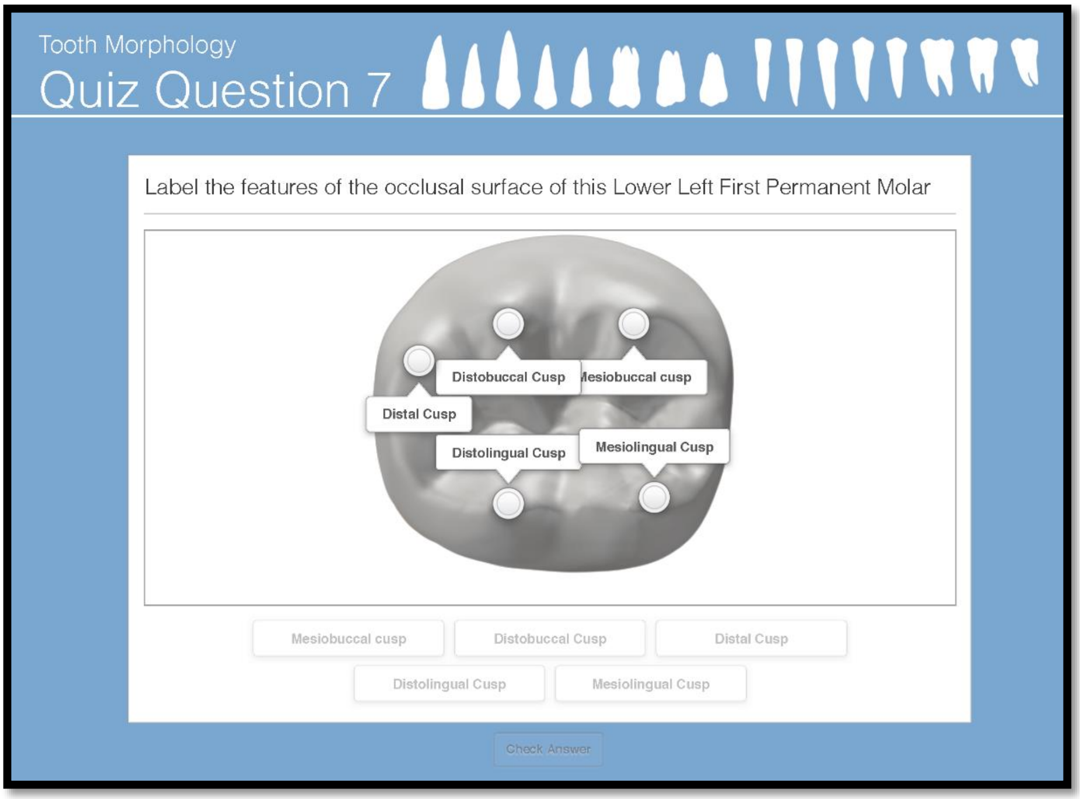

Tooth Morphology
Quiz Question 3
INTERACTIVE 3D MODEL
Identify this tooth
A. Permanent Upper Left First Molar
B. Permanent Lower Left Second Molar
C. Permanent Upper Left Third Molar
D. Permanent Upper Left Second Molar
Check Answer

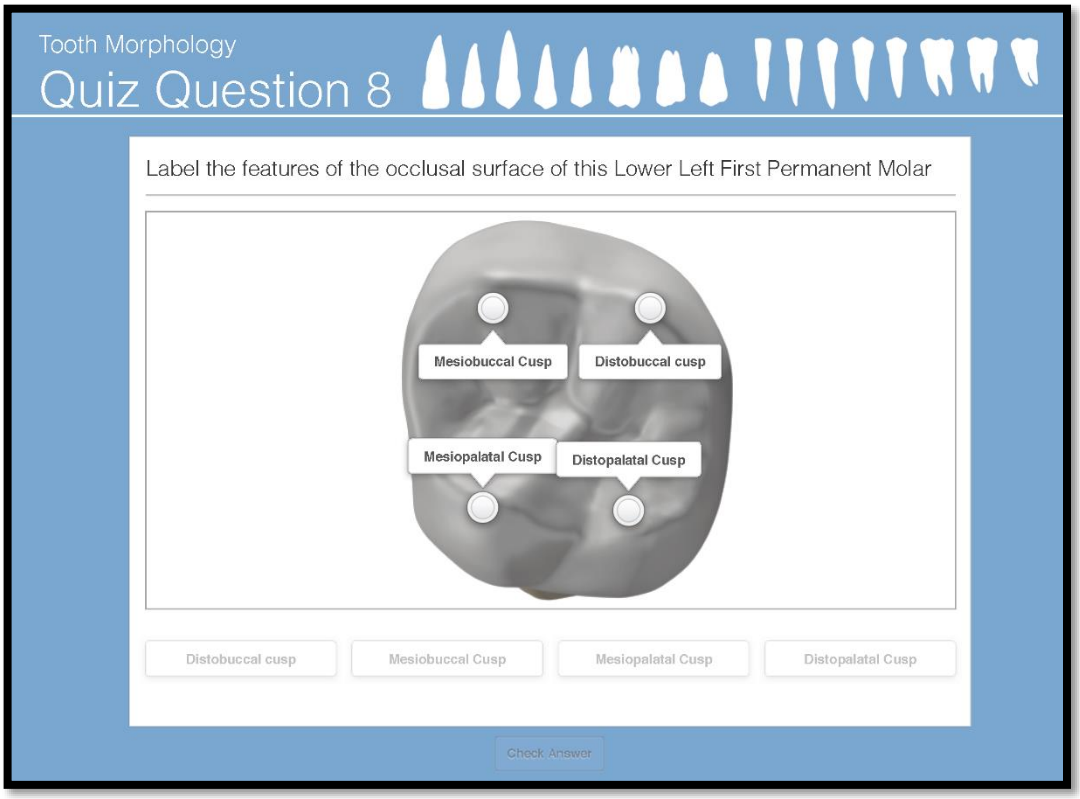

Tooth Morphology
Quiz Question 4
INTERACTIVE 3D MODEL
Identify this tooth
A. Upper Right First Premolar
B. Upper Right Second Premolar
C. Lower Right First Premolar
D. Lower Right Second Premolar
Check Answer

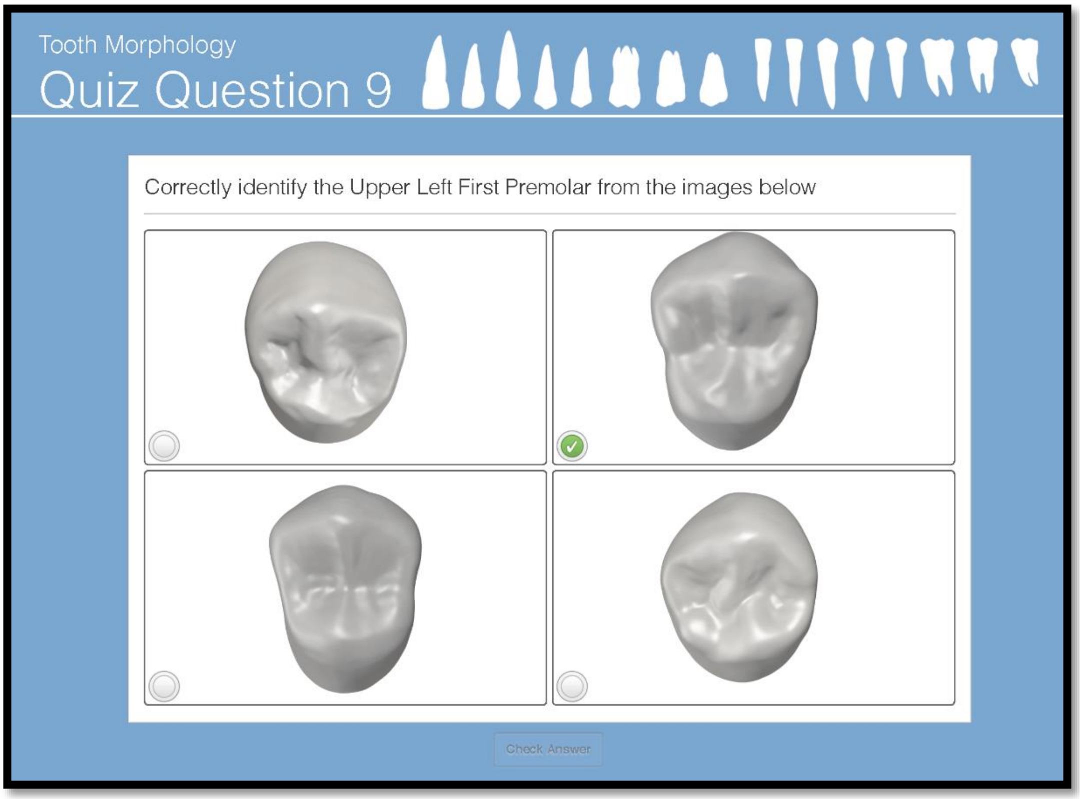

Tooth Morphology
Quiz Question 5
INTERACTIVE 3D MODEL
Identify this tooth
A. Permanent Lower Left Canine
B. Permanent Lower Right Canine
C. Permanent Upper Left Canine
D. Permanent Upper Right Canine
Check Answer

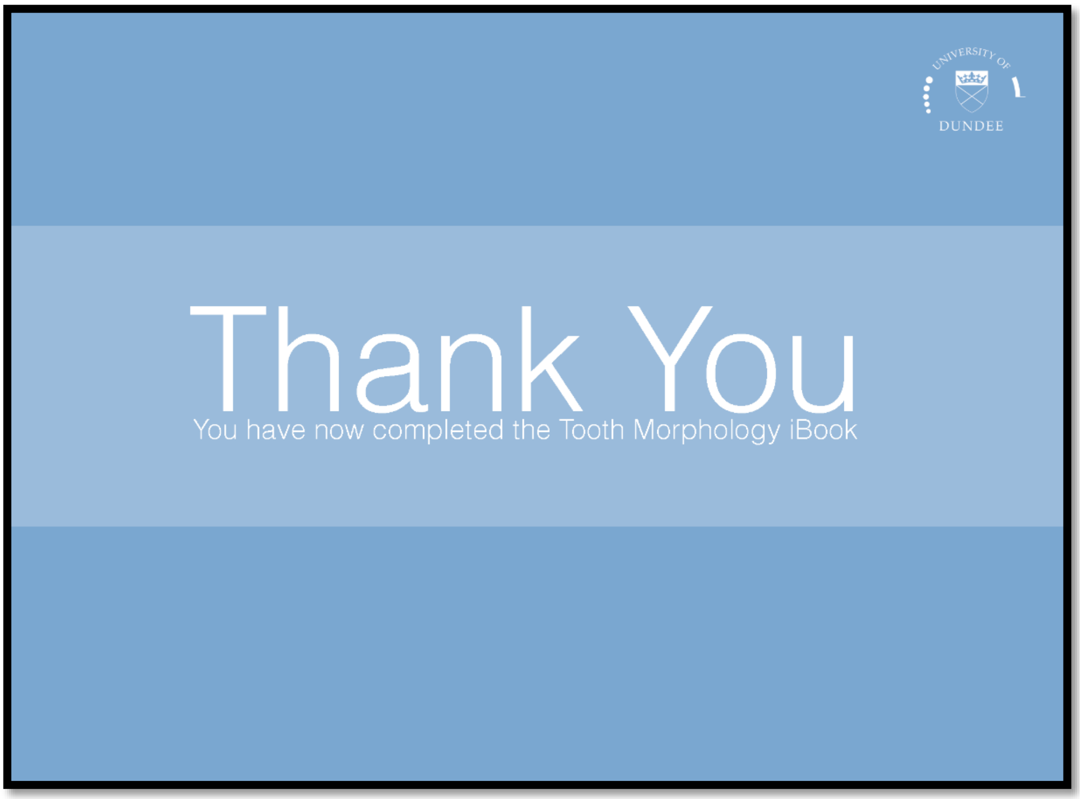

Tooth Morphology
Quiz Question 5
INTERACTIVE 3D MODEL
Identify this tooth
A. Permanent Lower Right First Molar
B. Permanent Lower Left Third Molar
C. Permanent Lower Second Molar
D. Permanent Lower Right Third Molar
Check Answer


Tooth Morphology
Quiz Question 6
The questions below will test your knowledge of the permanent incisors
Question 1 of 2
Looking at the incisal view of the teeth below, which teeth are in the illustration?
A. Tooth 11 and 12
B. Tooth 21 and 22
C. Tooth 31 and 32
D. Tooth 41 and 42
Check Answer
Q1
Q2
Touch the boxes above for more feedback on the answers of each question


Tooth Morphology
Quiz Question 7
Label the features of the occlusal surface of this Lower Left First Permanent Molar
Distobuccal Cusp
Mesiobuccal cusp
Distal Cusp
Distolingual Cusp
Mesiolingual Cusp
Mesiobuccal cusp
Distobuccal Cusp
Distal Cusp
Distolingual Cusp
Mesiolingual Cusp
Check Answer


Tooth Morphology
Quiz Question 8
Label the features of the occlusal surface of this Lower Left First Permanent Molar
Mesiobuccal Cusp
Distobuccal cusp
Mesiopalatal Cusp
Distopalatal Cusp
Distobuccal cusp
Mesiobuccal Cusp
Mesiopalatal Cusp
Distopalatal Cusp
Check Answer


Tooth Morphology
Quiz Question 9
Correctly identify the Upper Left First Premolar from the images below
Check Answer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Thank You
You have now completed the Tooth Morphology iBook

COMING SOON! DUNDEE DENTAL SCHOOL 3D PRINTED TEETH AIR-FIX KIT

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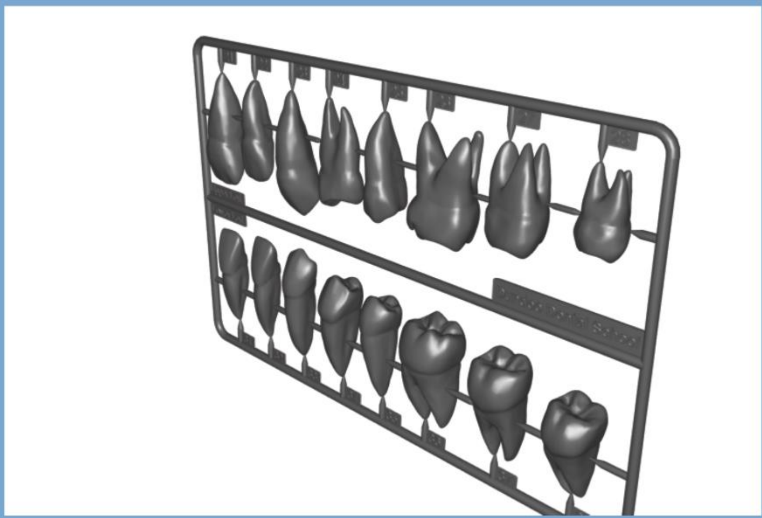

Soon you will be given your own Dundee Dental School 3D printed Teeth air-fix kit to use alongside this tooth morphology iBook. Coming soon!

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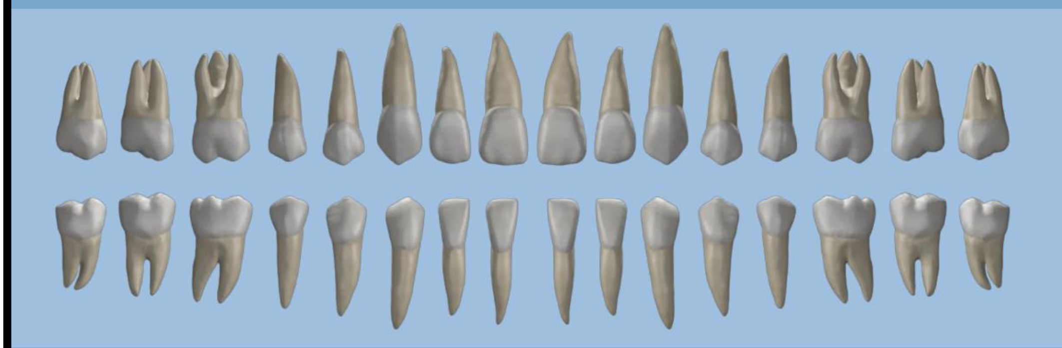

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APPENDIX 7: QUESTIONNAIRE USED IN THE TOOTH MORPHOLOGY STUDY

• The Tooth Morphology iBook •

Please choose the best answer for each of the following statements

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
The iBook was easy to use	○	○	○	○	○
The layout was well designed	○	○	○	○	○
The use of the iBook didn't really facilitated my learning	○	○	○	○	○
This teaching method motivates me to learn	○	○	○	○	○
The volume of information in 3D was appropriate	○	○	○	○	○
I am satisfied with the 360 degree rotation models	○	○	○	○	○
The 3D content was of poor quality	○	○	○	○	○
I have enjoyed learning Tooth Morphology with the 3D interactive iBook	○	○	○	○	○
In future, I would prefer to learn other areas of Dentistry with the 3D interactive iBook rather than with a textbook	○	○	○	○	○
I really liked the iBook's user interface	○	○	○	○	○

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
iBook should be made available for all dental students to learn Tooth Morphology	○	○	○	○	○
Learning Tooth Morphology seems easier with a textbook book rather than with the iBook	○	○	○	○	○
I feel more confident learning with iBook than with a textbook	○	○	○	○	○
I would prefer if lectures were replaced by iBook	○	○	○	○	○
The iBook provided material that was not otherwise available to me	○	○	○	○	○
I feel the iBook was of little help for the practical exam preparation	○	○	○	○	○

Is there anything else you would like to add about your experience with the Tooth Morphology iBook

Gender

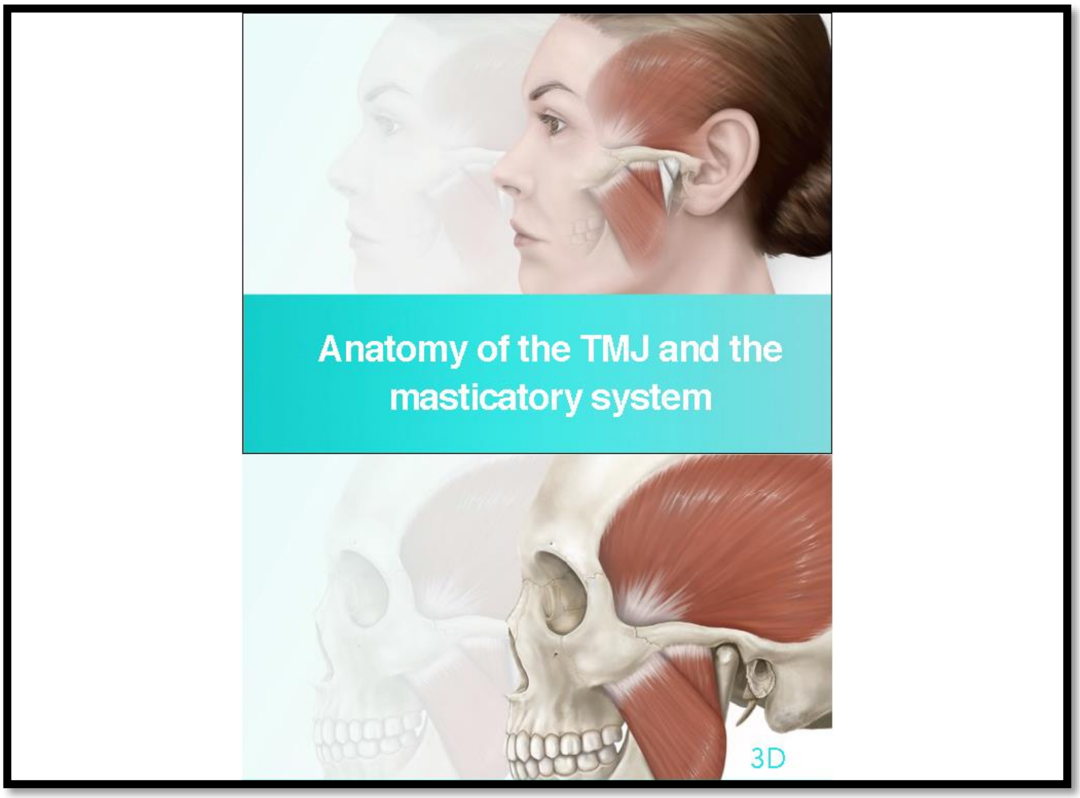
☐ F
☐ M

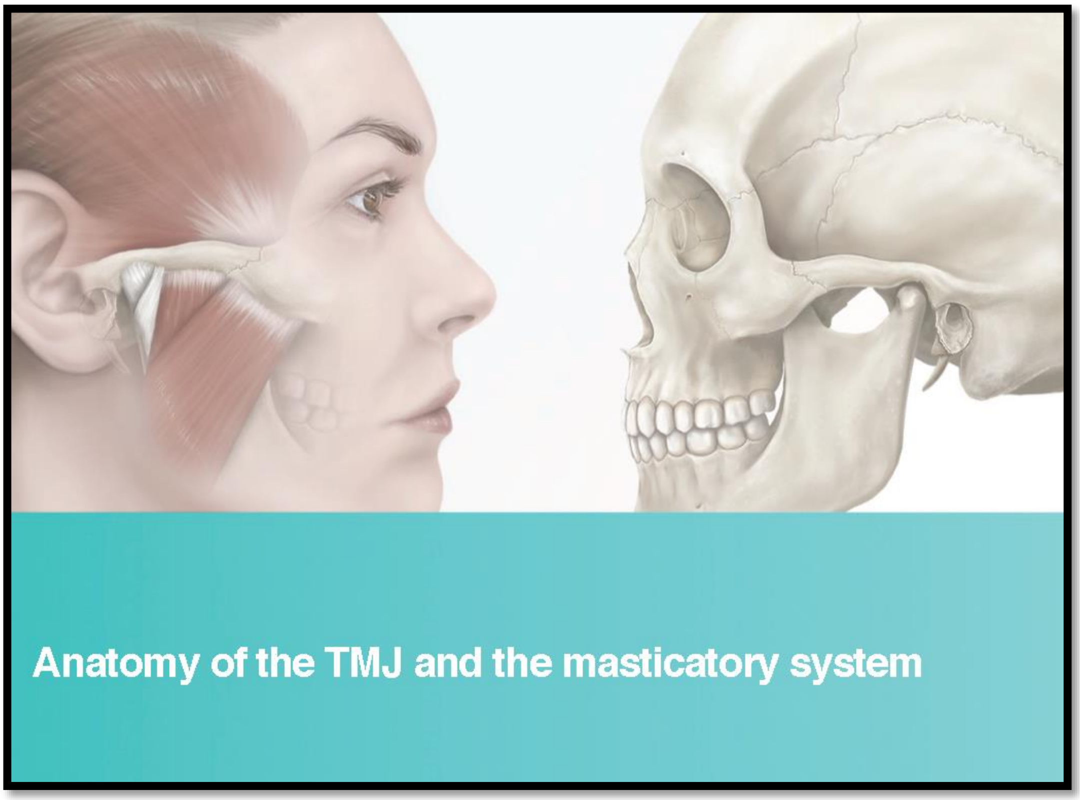
I want to volunteer for the focus group session

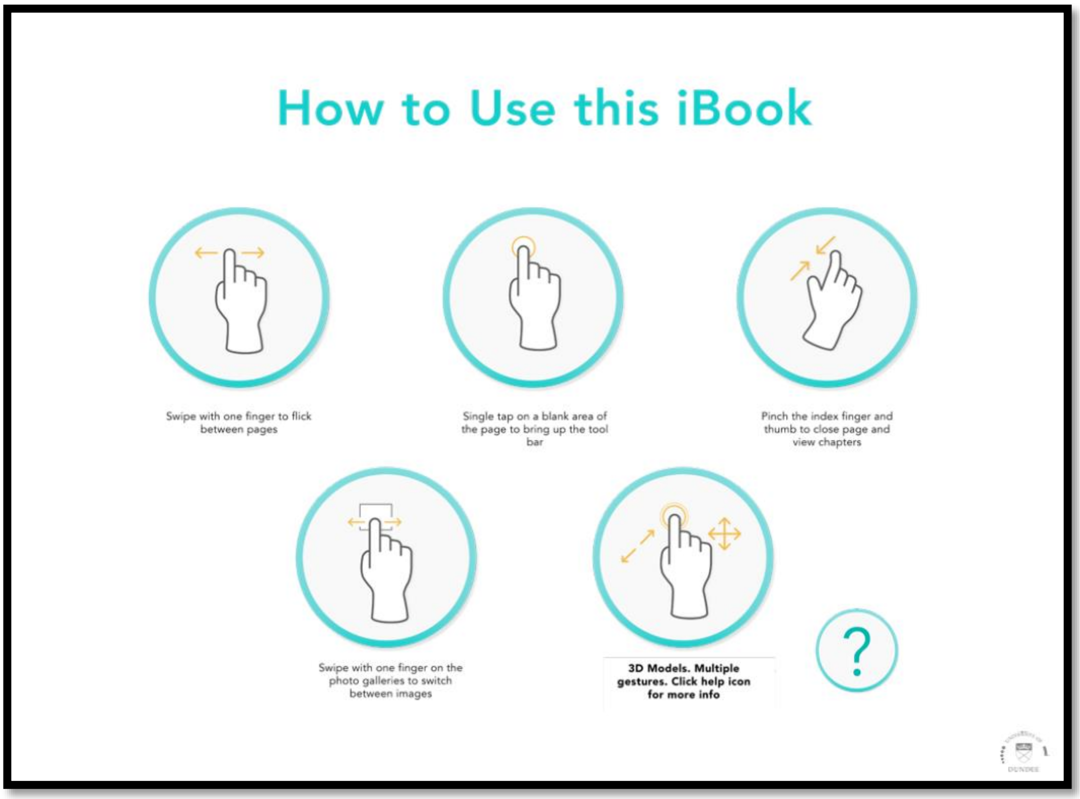
☐ Yes
☐ No

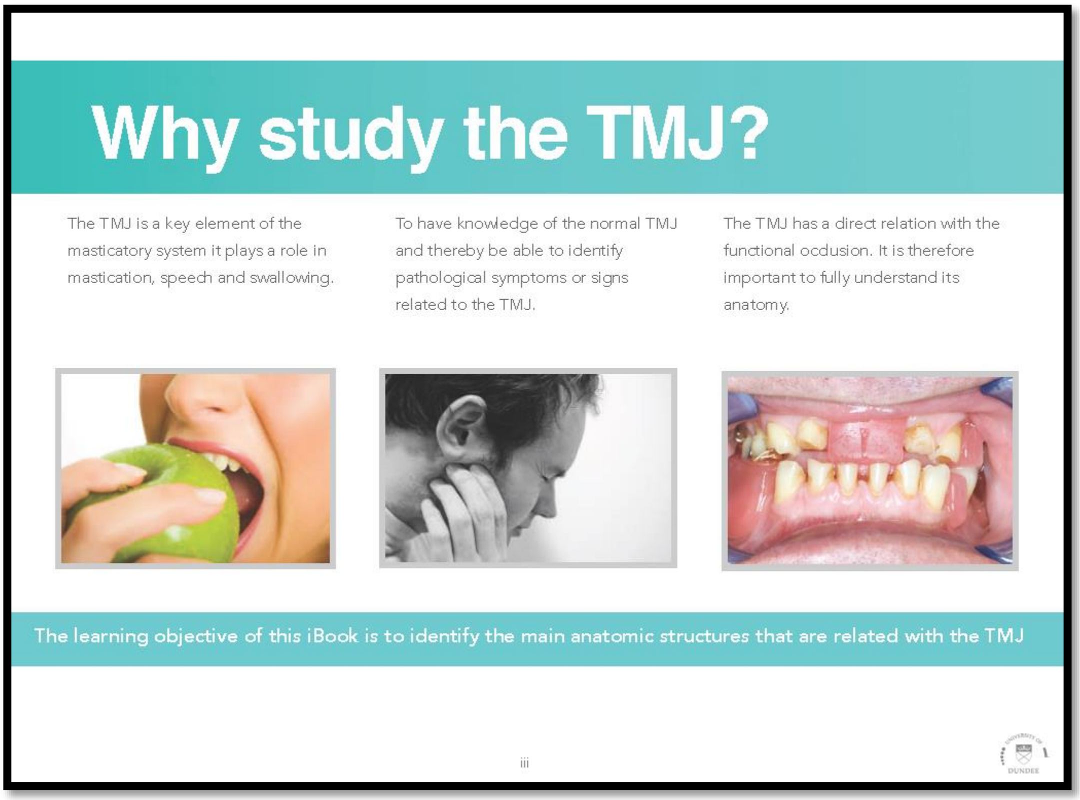
If "Yes", please write down your email. Thanks!

APPENDIX 8: THE TEMPOROMANDIBULAT JOINT IBOOK, 3D VERSION






How to Use this iBook
Swipe with one finger to flick between pages
Single tap on a blank area of the page to bring up the tool bar
Pinch the index finger and thumb to close page and view chapters
Swipe with one finger on the photo galleries to switch between images
3D Models. Multiple gestures. Click help icon for more info
?


Why study the TMJ?
The TMJ is a key element of the masticatory system it plays a role in mastication, speech and swallowing.
To have knowledge of the normal TMJ and thereby be able to identify pathological symptoms or signs related to the TMJ.
The TMJ has a direct relation with the functional occlusion. It is therefore important to fully understand its anatomy.
The learning objective of this iBook is to identify the main anatomic structures that are related with the TMJ
iii

THE FUNCTIONAL ANATOMY OF THE TEMPOROMANDIBULAR JOINT

The Bones

4

CHAPTER ONE

The Bones

The skeletal component of the human head are the skull and the mandible. The bones that are key in the functional anatomy of the TMJ are the Temporal Bone, the Maxilla and the Mandible.

In the model below these bones are highlighted along with the other bones that comprise the skull.

?

5

CHAPTER ONE : THE BONES

Temporal Bone

Right temporal bone, lateral view

The temporal bone is a key component of the TMJ as it articulates with the mandible.

The squamous portion of the temporal bone articulates with the mandibular condyle. The concave glenoid fossa, (or articular or mandibular fossa), receives the mandibular condyle. The degree of convexity varies from patient to patient and it determines the pathway of movement of the condyle. The posterior roof of the glenoid fossa is very thin meanwhile the articular eminence, located anteriorly is thicker able to support bigger loads. The squamotympanic fissure is posterior to the glenoid fossa.

CHAPTER ONE : THE BONES

Temporal Bone

?

CHAPTER ONE : THE BONES

Mandible

Mandible, lateral right view

The mandible articulates with the temporal bone.

Four areas can be identified:

1. The alveolus - containing the teeth.
2. The body - supporting the alveolus
3. The ramus - that terminates in the coronoid process and the condyle
4. The condyle - which is the articulating portion.

The mandible is attached to the cranium by ligaments, muscles and other soft-tissues.

CHAPTER ONE : THE BONES

Mandible

?

CHAPTER ONE : THE BONES

Maxilla

Right maxilla, lateral view

1 of 11

The maxilla contain the the upper teeth and is one of the main bones of the facial skeleton.

Its superior border forms the floor of the nasal cavity and the floor of the orbit. Inferiorly its forms the palate and the alveolar ridges.

CHAPTER ONE : THE BONES

Maxilla

?

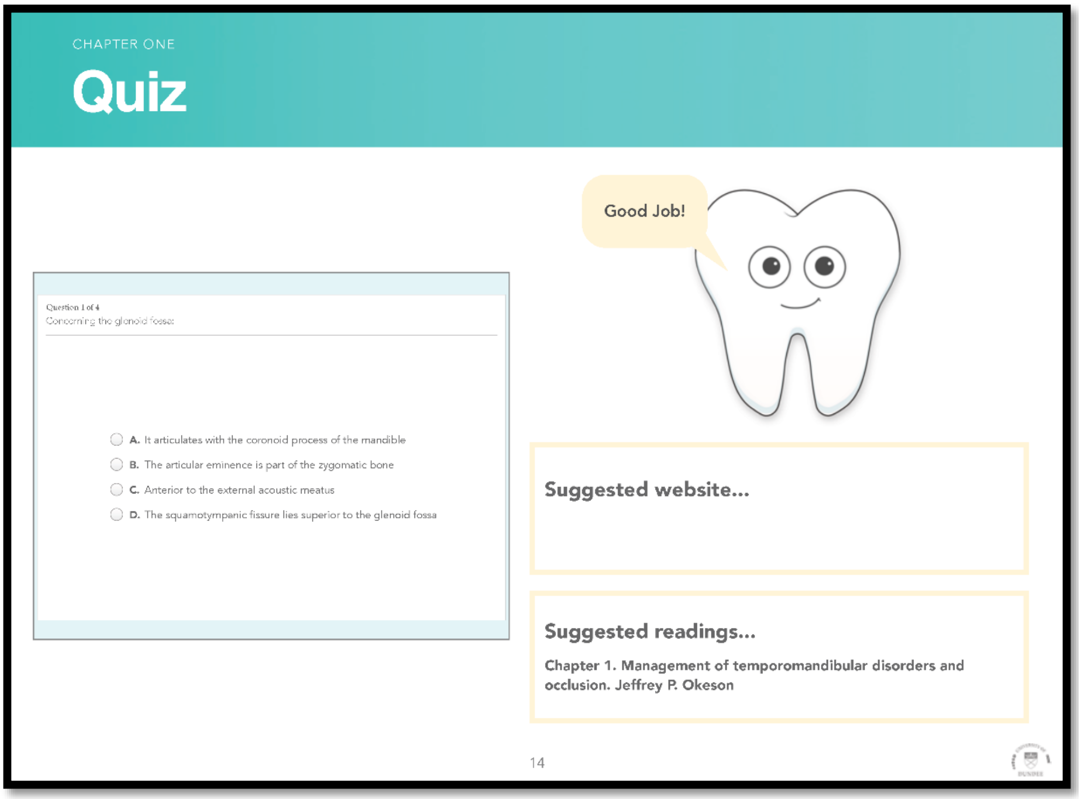
Palatine Bone

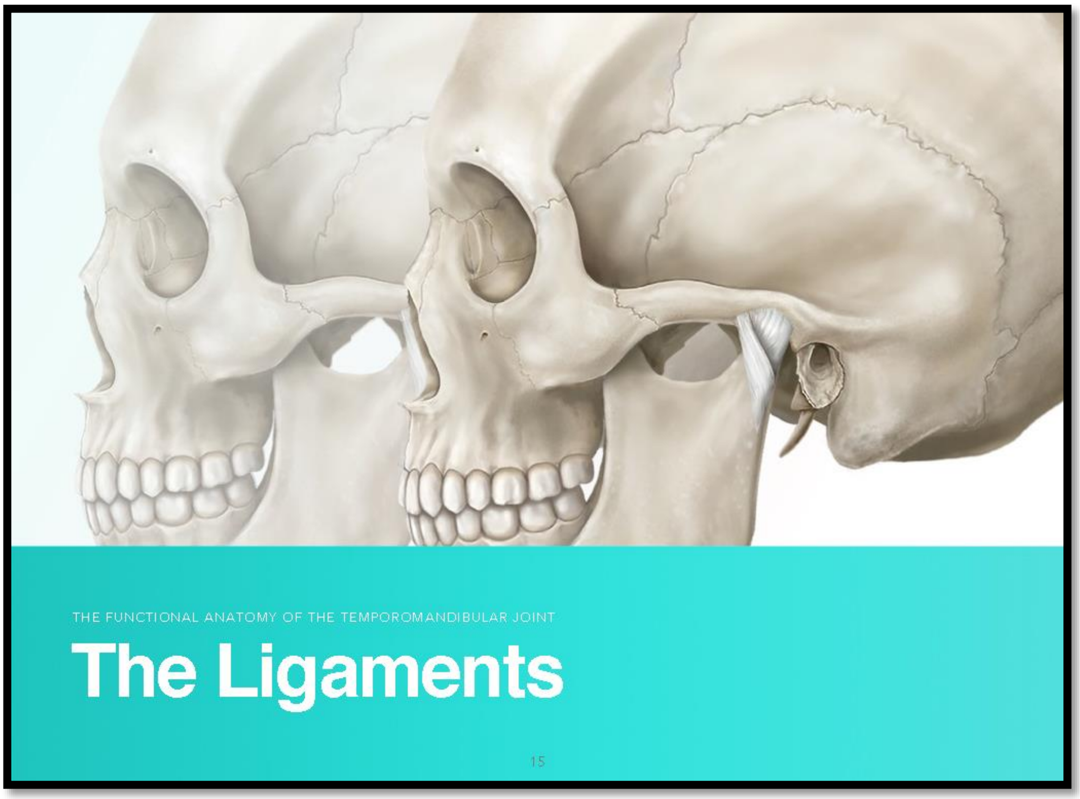
Palatine bone, inferior view. Dentate arch

The palatine bone is a complex, L shaped bone located posterior to the maxilla. It forms the posterior floor and lateral wall of the nasal cavity, the hard palate of the oral cavity and contributes to the floor of the orbit. It has no direct relation with the temporomandibular joint but is was included as it is the posterior extension of the maxilla.

Palatine Bone

?


CHAPTER ONE
Quiz
Question 1 of 4
Concerning the glenoid fossa:
A. It articulates with the coronoid process of the mandible
B. The articular eminence is part of the zygomatic bone
C. Anterior to the external acoustic meatus
D. The squamotympanic fissure lies superior to the glenoid fossa
Good Job!
Suggested website...
Suggested readings...
Chapter 1. Management of temporomandibular disorders and occlusion. Jeffrey P. Okeson
14


THE FUNCTIONAL ANATOMY OF THE TEMPOROMANDIBULAR JOINT
The Ligaments
15

CHAPTER TWO

The Ligaments

Ligaments support the TMJ.

The function of the ligaments is to protect the TMJ by limiting the movements of the joint. The temporomandibular joint is protected by six groups of ligaments: three directly associated with TMJ and three remote accessory ligaments.

TMJ ligaments

1. The capsular ligament
1. The discal ligament
2. The temporomandibular ligament

Accessory ligaments

3. The sphenomandibular ligament
4. The stylomandibular ligament
5. Pterygomandibular raphe

?

CHAPTER TWO : THE LIGAMENTS

The Capsular Ligament

The **fibrous capsule** itself acts as a ligament.

It's fibres originate superiorly on the temporal bone along the borders of the articular surface of the glenoid fossa. The fibres insert in the neck of the condyle allowing the ligament to resist medial, lateral or inferior forces.

Its functionality avoids dislocation of the articular surfaces and retains the synovial fluid that keeps the joint lubricated.

Proprioception of the position and movement of the joint is given by receptors in this ligament.

?

CHAPTER TWO : THE LIGAMENTS

The Discal Ligament

These are two small ligaments:

The **medial discal ligament** attaches the medial edge of the disc to the medial pole of the condyle.

The **lateral discal ligament** attaches the lateral pole of the condyle with the lateral portion of the disc.

The function of these ligaments is to restrict the medial or lateral movement of the disc, while still allowing the disc to move anteriorly and posteriorly during the hinge and sliding movement of the joint.

?

CHAPTER TWO : THE LIGAMENTS

The Temporomandibular Ligament

The **temporomandibular ligament** originates on the lateral aspect of the articular eminence. It fibres follow an oblique direction which then insert on the posterior surface of the neck of the condyle.

This ligament restricts posterior, lateral and inferior movement of the condyle. In addiction, it restricts medial movement of the contralateral condyle.

?

CHAPTER TWO : THE LIGAMENTS

The Accessory Ligaments

The TMJ has three accessory ligaments:

1. The **sphenomandibular ligament** originates at the spine of the sphenoid bone and inserts in the lingula located in the inner part of the ramus.

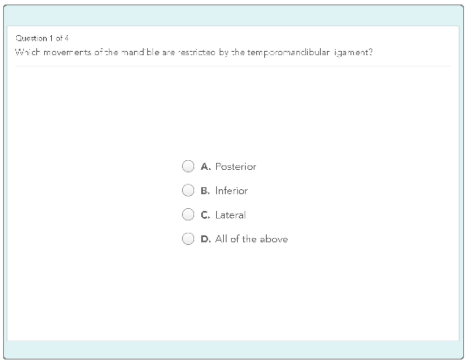
2. The **stylomandibular ligament** originates at the styloid process and extends downwards and forward to the medial aspect of the angle of the mandible. It's function is to restrict the protrusive movement of the mandible.

3. The **pterygomandibular raphe** originates from the pterygoid hamulus and extends to the retromolar region. The raphe is a landmark for local anaesthesia. It is also the origin of the Buccinator and superior pharyngeal constrictor muscles.

?

CHAPTER TWO : THE LIGAMENTS

Quiz



Question 1 of 4

Which movements of the mandible are restricted by the temporomandibular ligament?

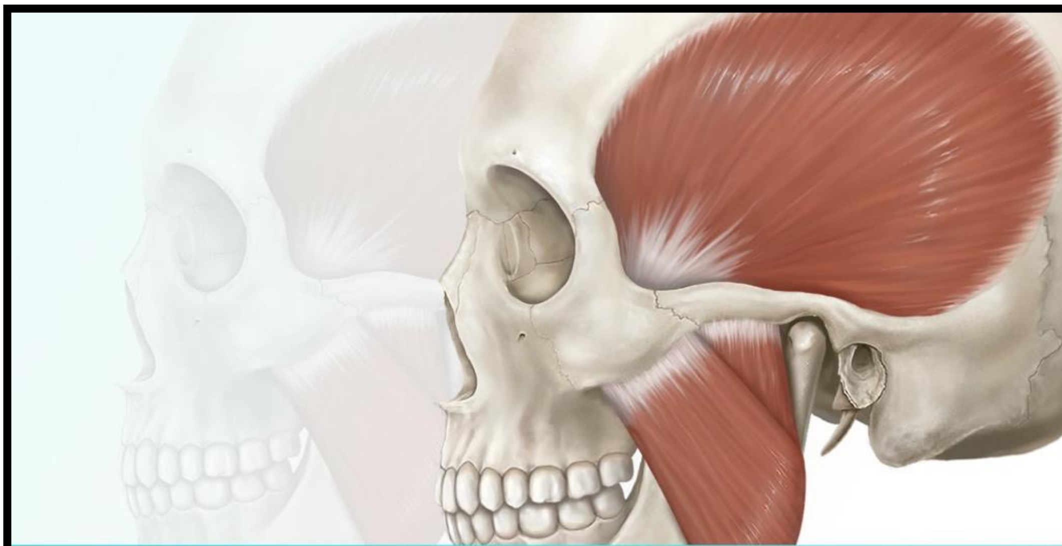
- **A.** Posterior
- **B.** Inferior
- **C.** Lateral
- **D.** All of the above

Suggested website...

https://www.innerbody.com/

Suggested readings...

http://jaoa.org/article.aspx?articleid=2094120



THE FUNCTIONAL ANATOMY OF THE TEMPOROMANDIBULAR JOINT

The Muscles

22

CHAPTER THREE

The Muscles

There are five are the main muscles involved in mastication:

1. The masseter
2. The temporalis
3. The medial pterygoid
4. The lateral pterygoid
5. The digastric

?

23

CHAPTER THREE : THE MUSCLES

The Masseter

The **masseter** originates at the zygomatic arch and bone and inserts onto the lateral aspect of the lower border and angle of the ramus of the mandible.

The superficial fibres run downward and backwards. While the deep fibres run vertically to the insertion area.

Its main function is to elevate the mandible. As a secondary function the superficial fibres are active during protrusion. The masseter is innervated by the masseteric nerve and blood supplied by the masseteric artery.

?

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CHAPTER THREE : THE MUSCLES

The Temporalis

The **temporalis** originates from the inferior temporal line and fossa and the lateral surface of the skull. It is a fan-shape muscle that inserts onto the coronoid process and anterior border of the ascending ramus.

Its function is to elevate the mandible but its horizontal fibres help with retrusive movements.

The temporalis is innervated by the deep temporal nerve branch of the trigeminal nerve. Blood supply is given by the anterior, posterior and superficial temporal arteries.

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25

The Medial Pterygoid

The **medial pterygoid** has two heads; the main one originates from the medial aspect of the lateral pterygoid plate, the minor head originated form the maxillary tuberosity. The fibres then insert onto the medial surface of the angle of the mandible following a downwards, backward and outward direction.

Its primary action is to elevate the jaw and also aids protrusive movements and, if unilateral contraction, lateral excursions of the mandible. Blood supply is given by the pterygoid brach of the maxillary artery. It is innervated by medial pterygoid nerve.

?

The Lateral Pterygoid

The **lateral pterygoid** is a complex and poorly understood muscle. It has two heads that appear to function differently. These are the superior lateral pterygoid and the inferior lateral pterygoid.

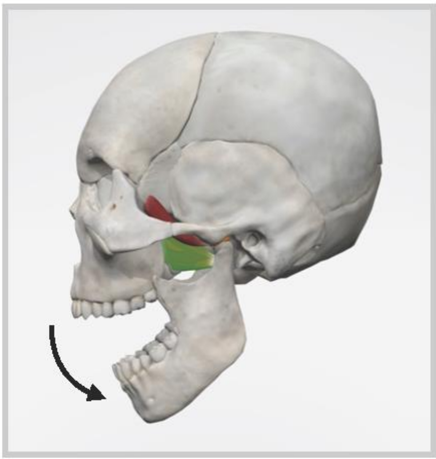
?

CHAPTER THREE : THE MUSCLES

The Inferior Lateral Pterygoid

The inferior head of the lateral pterygoid originates from the lateral surface of the lateral pterygoid plate and inserts into the pterygoid fovea on the neck of the condyle.

Its main function is to protrude the mandible when it contracts bilaterally. However, when one side contracts, the mandible moves to the opposite side. When working in conjunction with jaw depressor muscles it facilitates wide opening.



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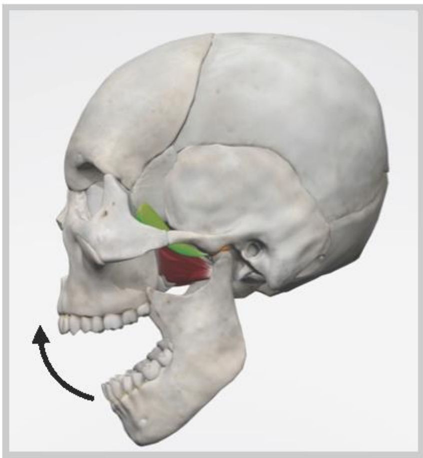
CHAPTER THREE : THE MUSCLES

The Superior Lateral Pterygoid

The superior head of the lateral pterygoid is smaller than than the inferior head. This section originates in the infra-temporal surface of the greater sphenoid wing and inserts onto the articular capsule and the disc of the TMJ.

This muscle is active during closing movement of the mandible. It is especially active when maximum bite force is generated, for example during clenching. Therefore, it can be symptomatic in patients with TMJ disorders.



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CHAPTER THREE : THE MUSCLES

The Digastric

The **digastric muscles** is involved in jaw opening movement. It has two bellies - anterior and posterior.

Its anterior belly originates from the digastric fossa of the mandible and the posterior belly originates from the mastoid notch. Both insert into the intermediate tendon that is attached to the hyoid bone by a fibrous loop.

When the hyoid bone is fixed, the anterior belly acts as a jaw depressor. If the hyoid bone is not fixed, the digastric muscles act to raise the hyoid bone during swallowing.

?

CHAPTER THREE : THE MUSCLES

Quiz

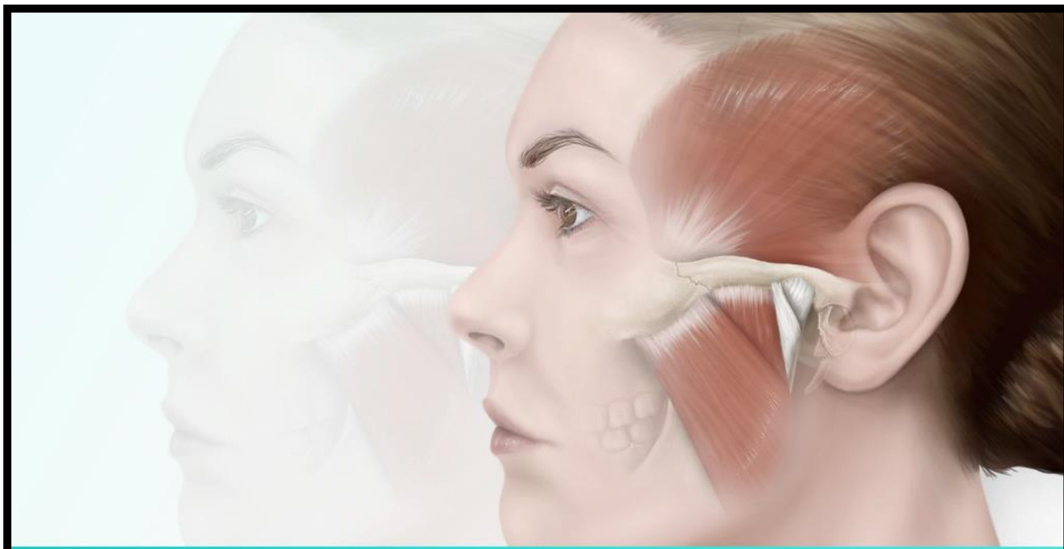
Question 1 of 4
Regarding the masseter muscle.

- A. It contributes to jaw opening during mastication
- B. Its superficial fibres insert in the anterior border of the ramus
- C. Its deep fibres run vertically
- D. Contraction of superficial fibres help retrusive jaw movements

Suggested website...

https://www.innerbody.com/anatomy/muscular/head-neck

Suggested readings...



THE FUNCTIONAL ANATOMY OF THE TEMPOROMANDIBULAR JOINT

The Joint

CHAPTER FOUR: THE JOINT

The Temporomandibular Joint

The complexity of the TMJs lies in the existence of two joints connected to one bone. This allows the generation of simultaneous and individual movements of each of the joints.

During mastication and physiological movement of the jaw several structures are activated to obtain the resulting motion.

The TMJ is a compound joint and its functionality and structures can be divided in two:

1. The joint system
2. The condyle-disc complex and the glenoid fossa.

The TMJ is mainly innervated by auriculotemporal nerve.

?

CHAPTER FOUR: THE JOINT

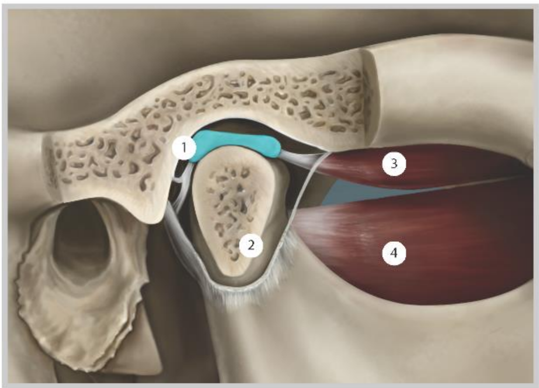
The Articular System

The condyle-disc complex articulates with the glenoid fossa of the temporal bone. The disc is intimately attached to the condyle so it can only rotate in the articular surface of the condyle. However, as the disc is not tightly attached to the glenoid fossa, sliding and free translation of the condyle-disc complex can occur. Both systems are attached to each other mainly ligaments - including the capsule.

CHAPTER FOUR: THE JOINT

The Disc

The disc is a avascular cartilage which allows the normal movement of the jaw. Anteriorly is continued by the attachment of the superior pterygoid muscle. Posteriorly the disc is continued by a retrodiscal tissue which is highly vascular and contain nerves. Laterally, the disc is fixed by the discal ligaments.

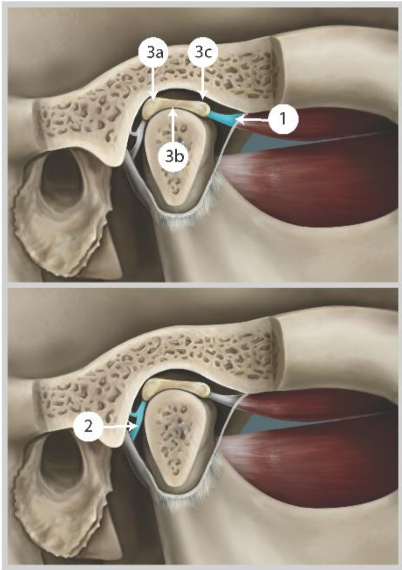


1. Disc; 2.Condyle; 3. Superior Lateral Pterygoid; 4. Inferior Lateral Pterygoid

?

CHAPTER FOUR: THE JOINT

The Disc



The articular disc has 5 zones

1. Anterior extension - is continuous with the superior head of the lateral pterygoid
2. Posterior extension - is densely innervated and has two layers:
   a. The upper layer which is vascular and elastic
   b. Lower layer which is fibrous.
3. Disc
   a. Anterior band
   b. Intermediate zone
   c. Posterior band

CHAPTER FOUR: THE JOINT

Blood supply and innervation

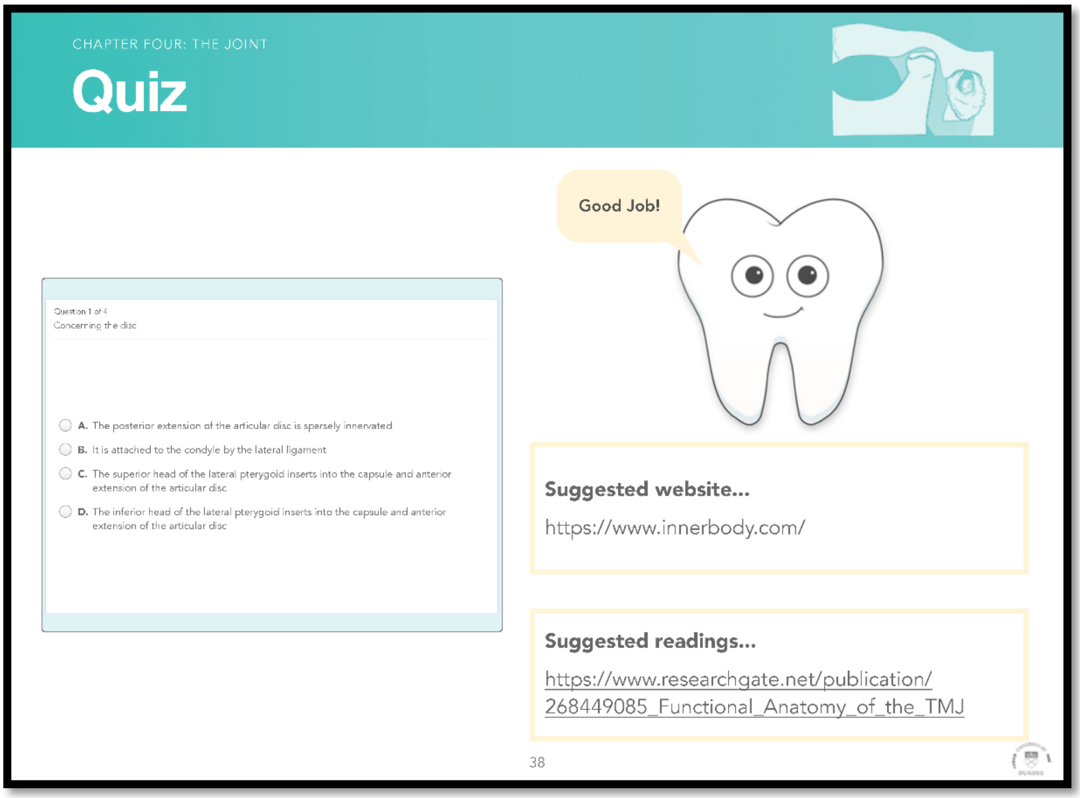
Blood Supply

The TMJ has a rich blood supply. It is supplied by the superficial temporal artery but also branches off the medial meningeal, the maxillary artery among others.

Innervation

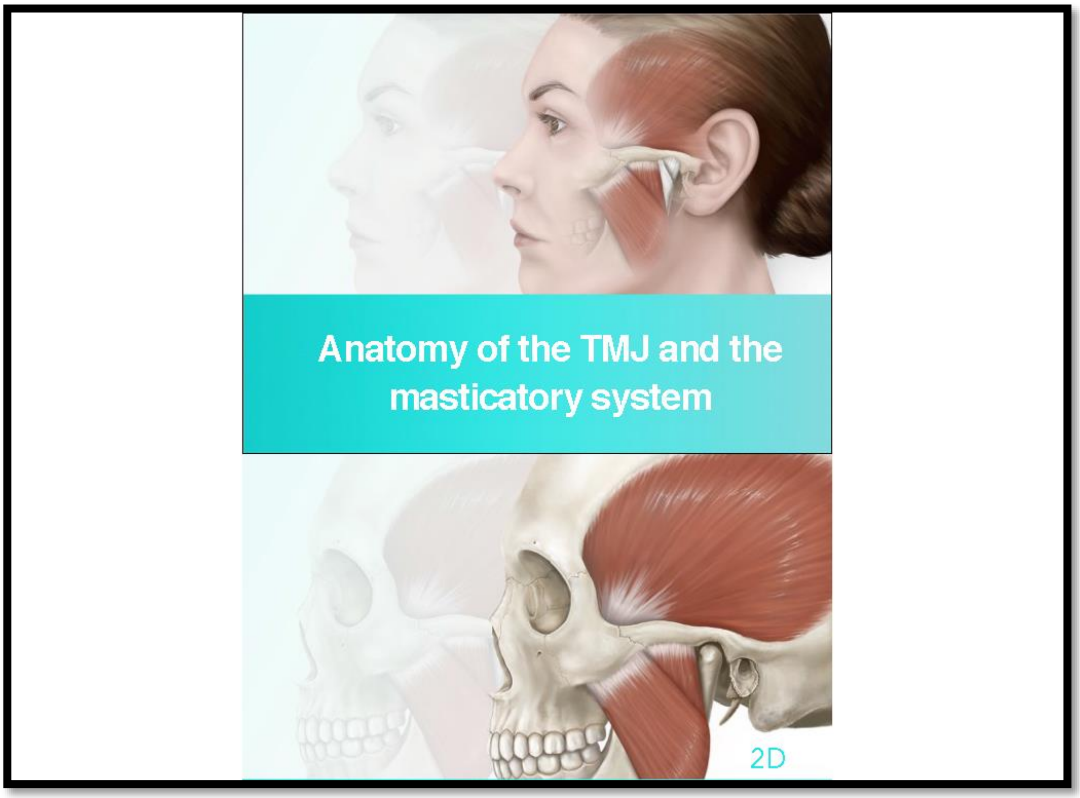
The TMJ is innervated by the auriculotemporal nerve. In addition it is also supplied by branches of the deep temporal masseteric nerve. These are all branches of the mandibular division of the trigeminal nerve.

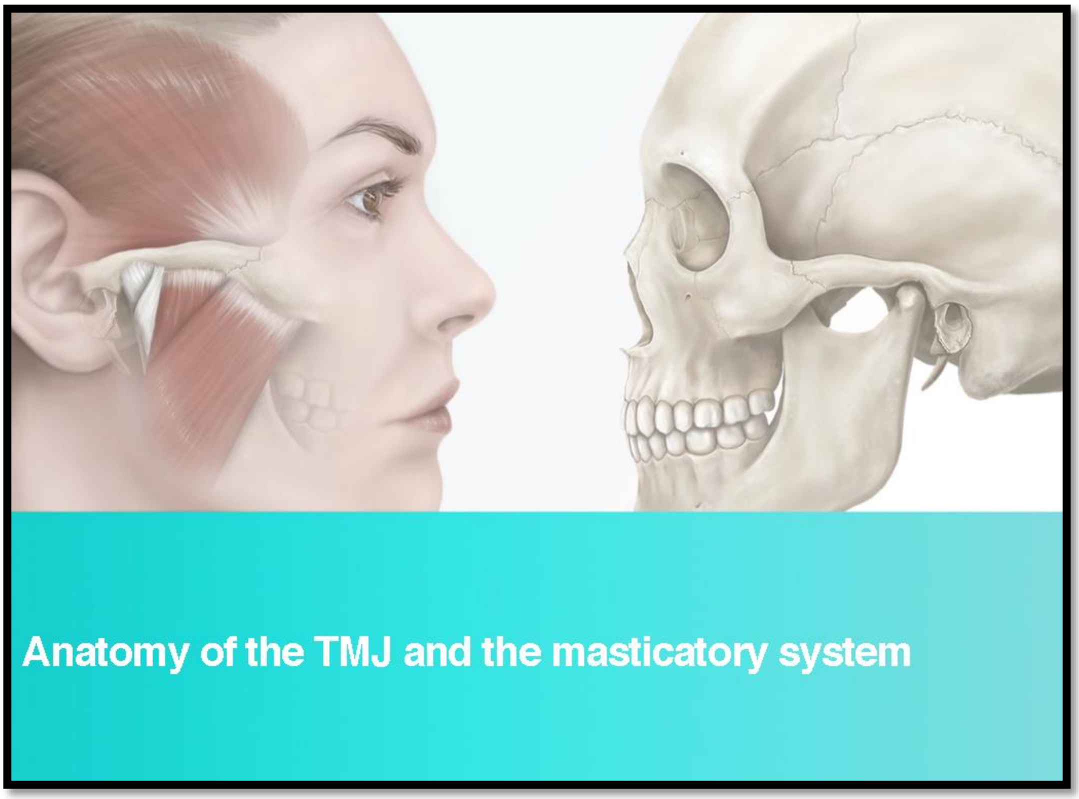
?

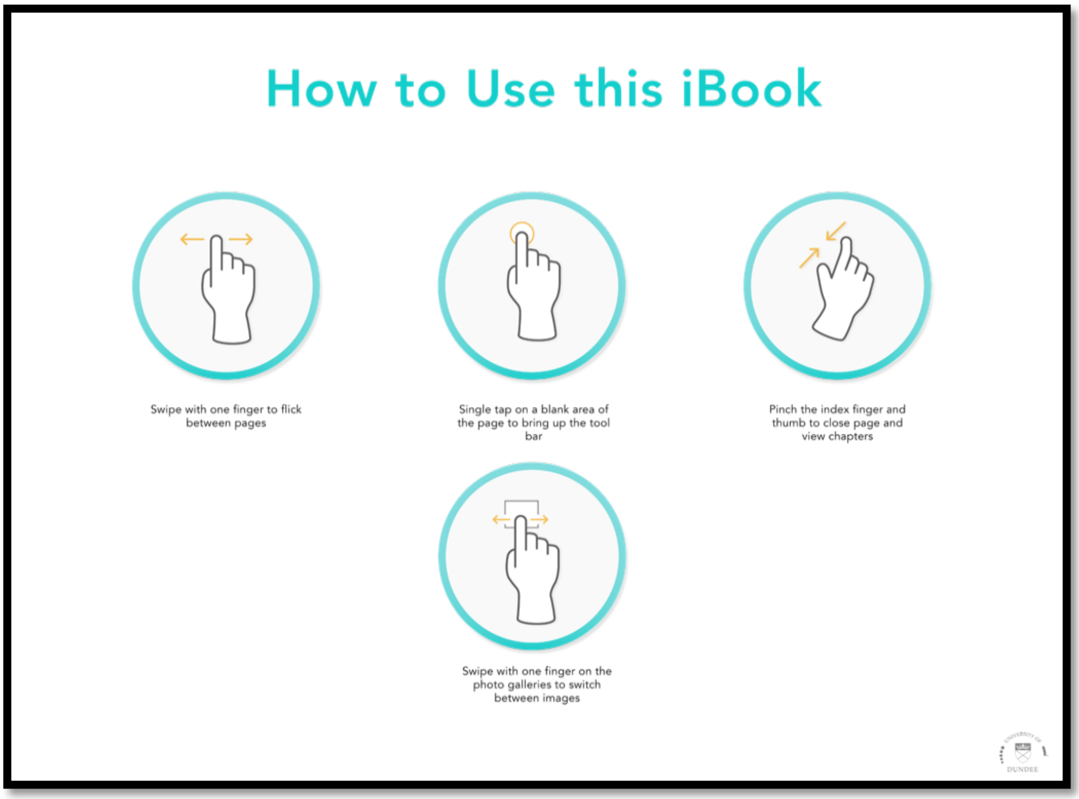


CHAPTER FOUR: THE JOINT
Quiz
Good Job!
Question 1 of 4
Concerning the disc
A. The posterior extension of the articular disc is sparsely innervated
B. It is attached to the condyle by the lateral ligament
C. The superior head of the lateral pterygoid inserts into the capsule and anterior extension of the articular disc
D. The inferior head of the lateral pterygoid inserts into the capsule and anterior extension of the articular disc
Suggested website...
https://www.innerbody.com/
Suggested readings...
https://www.researchgate.net/publication/268449085_Functional_Anatomy_of_the_TMJ
38

APPENDIX 9: THE TEMPOROMANDIBULAT JOINT IBOOK, 2D VERSION






How to Use this iBook
Swipe with one finger to flick between pages
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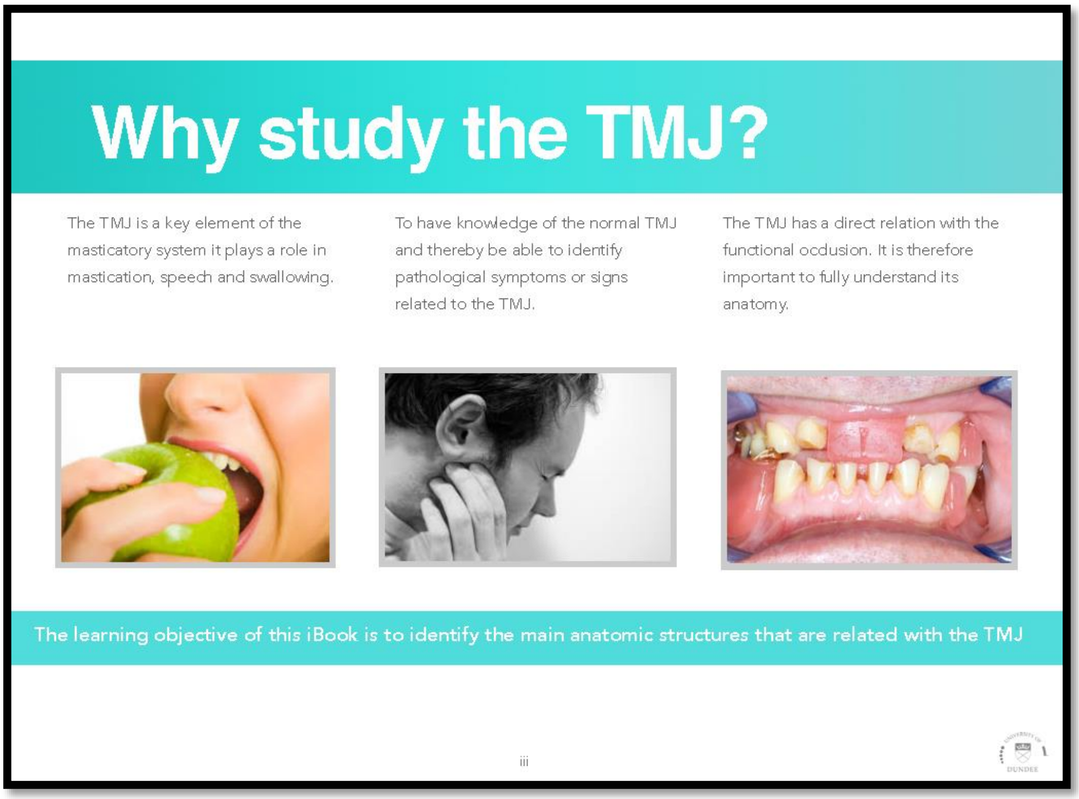
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The learning objective of this iBook is to identify the main anatomic structures that are related with the TMJ
iii

THE FUNCTIONAL ANATOMY OF THE TEMPOROMANDIBULAR JOINT

The Bones

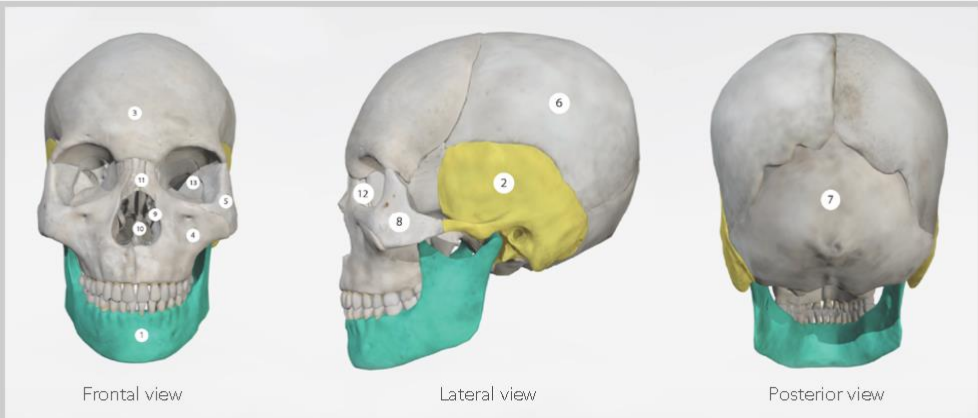
4

CHAPTER ONE

The Bones

The skeletal component of the human head are the skull and the mandible. The bones that are key in the functional anatomy of the TMJ are the Temporal Bone and the Mandible.

In the model below these bones are highlighted along with the other bones that comprise the skull.



1. Mandible; 2.Temporal bone; 3.Frontal Bone; 4. Maxilla; 5. Zygomatic bone; 6. Parietal bone; 7.Occipital bone; 8.Ethmoid; 9.Inferior nasal concha; 10. Vomer; 11. Nasal bone; 12. Lacrimal bone; 13. Sphenoid bone.

5

CHAPTER ONE : THE BONES

Temporal Bone

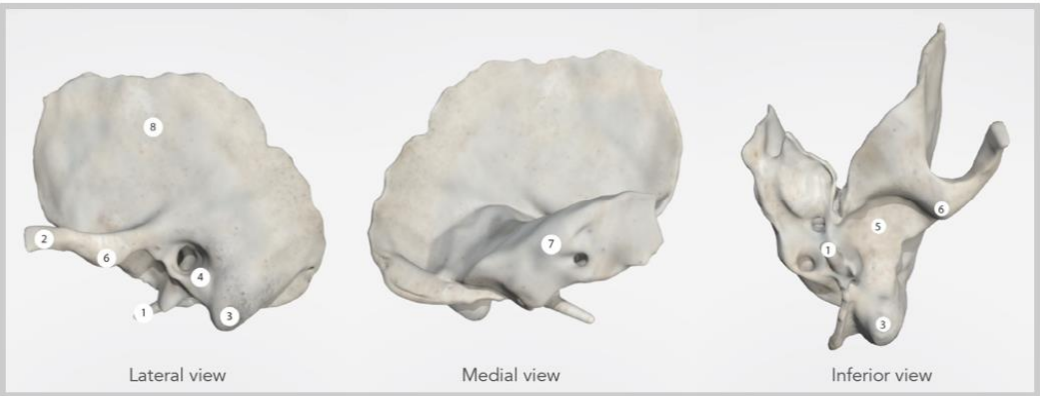
Right temporal bone, lateral view

The **temporal bone** is a key component of the TMJ as it articulates with the mandible.

The squamous portion of the temporal bone articulates with the mandibular condyle. The concave glenoid fossa, (or articular or mandibular fossa), receives the mandibular condyle. The degree of convexity varies from patient to patient and it determines the pathway of movement of the condyle. The posterior roof of the glenoid fossa is very thin meanwhile the articular eminence, located anteriorly is thicker able to support bigger loads. The squamotympanic fissure is posterior to the glenoid fossa.

CHAPTER ONE : THE BONES

Temporal Bone



1. Styloid process; 2. Zygomatic process (articulates with zygomatic bone); 3. Mastoid process; 4. External acoustic meatus; 5. Glenoid fossa (articulates with the condyle) 6. Articular eminence; 7. Internal auditory meatus; 8. Squamous portion.

CHAPTER ONE : THE BONES

Mandible

Mandible, lateral right view

The **mandible** articulates with the temporal bone.

Four areas can be identified:

1. The alveolus - containing the teeth.
2. The body - supporting the alveolus
3. The ramus - that terminates in the coronoid process and the condyle
4. The condyle - which is the articulating portion.

The mandible is attached to the cranium by ligaments, muscles and other soft-tissues.

CHAPTER ONE : THE BONES

Mandible

1. Condyle (articulates with the glenoid fossa); 2. Mandibular foramen; 3. Mental foramen; 4.Coronoid process; 5. Ramus 6. Angle of the ramus; 7. Alveolar ridge.

CHAPTER ONE : THE BONES

Maxilla

Right maxilla, lateral view

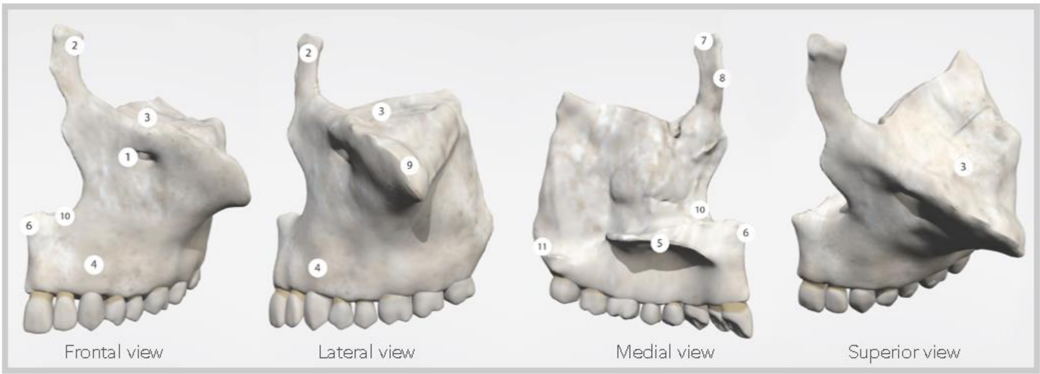
1 of 11

The **maxilla** contain the the upper teeth and is one of the main bones of the facial skeleton.

Its superior border forms the floor of the nasal cavity and the floor of the orbit. Inferiorly its forms the palate and the alveolar ridges.

CHAPTER ONE : THE BONES

Maxilla



1. Infra orbital foramen; 2. Frontal process; 3. Orbital surface; 4. Canine eminence; 5. Palatine process; 6. Anterior nasal spine; 7. Articulates with frontal bone; 8. Articulates with nasal bone; 9. Zygomatic process; 10. Nasal notch; 11. Maxillary tuberosity.

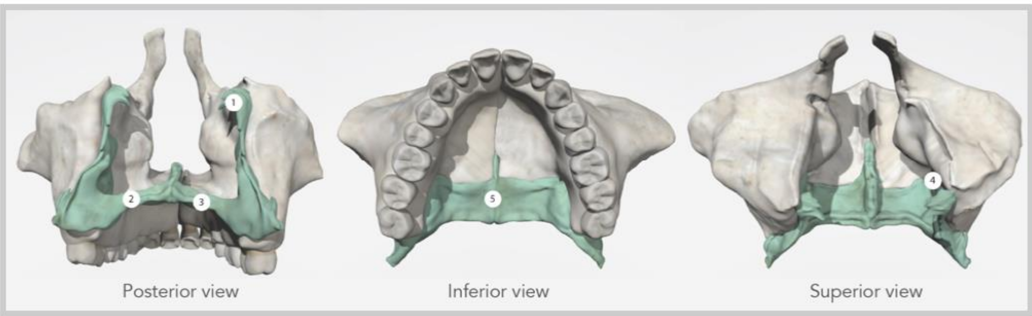
Palatine Bone

Palatine bone, inferior view. Dentate arch

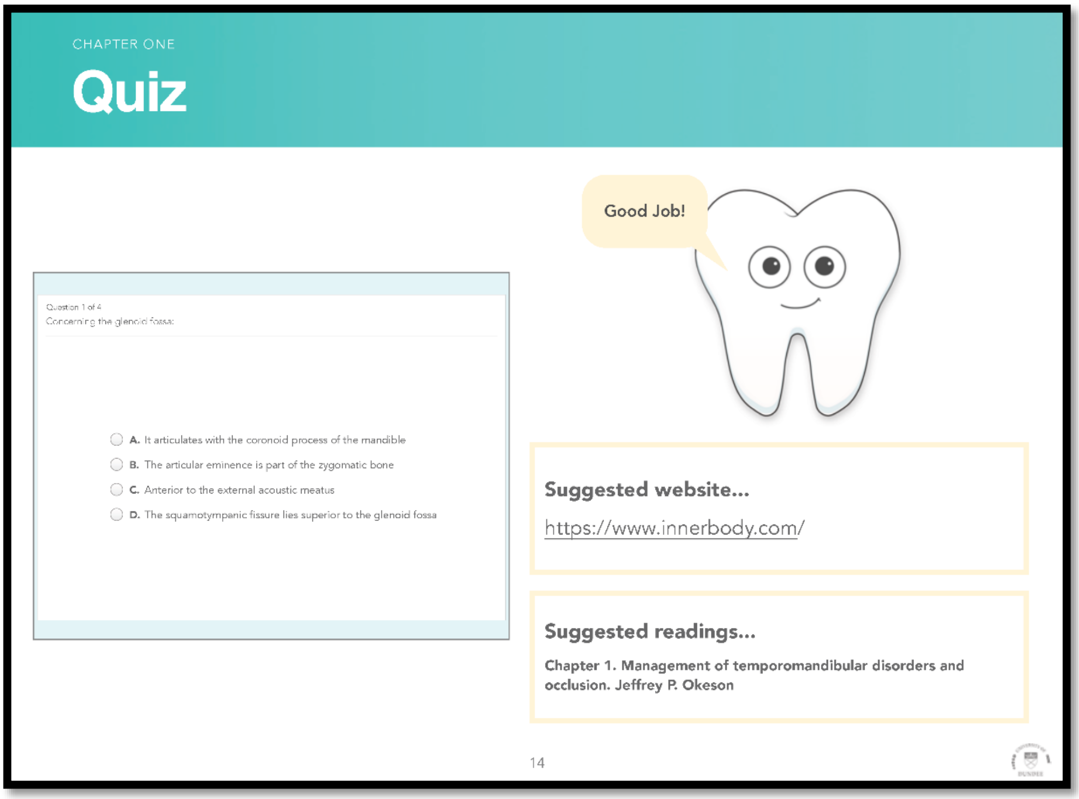
The **palatine bone** is a complex, L shaped bone located posterior to the maxilla. It forms the posterior floor and lateral wall of the nasal cavity, the hard palate of the oral cavity and contributes to the floor of the orbit. It has no direct relation with the temporomandibular joint but is was included as it is the posterior extension of the maxilla.

CHAPTER ONE : THE BONES

Palatine Bone



1. Orbital process; 2. Left palatine bone; 3. Right palatine bone; 4. Perpendicular plate; 5. Horizontal plate


CHAPTER ONE
Quiz
Question 1 of 4
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D. The squamotympanic fissure lies superior to the glenoid fossa
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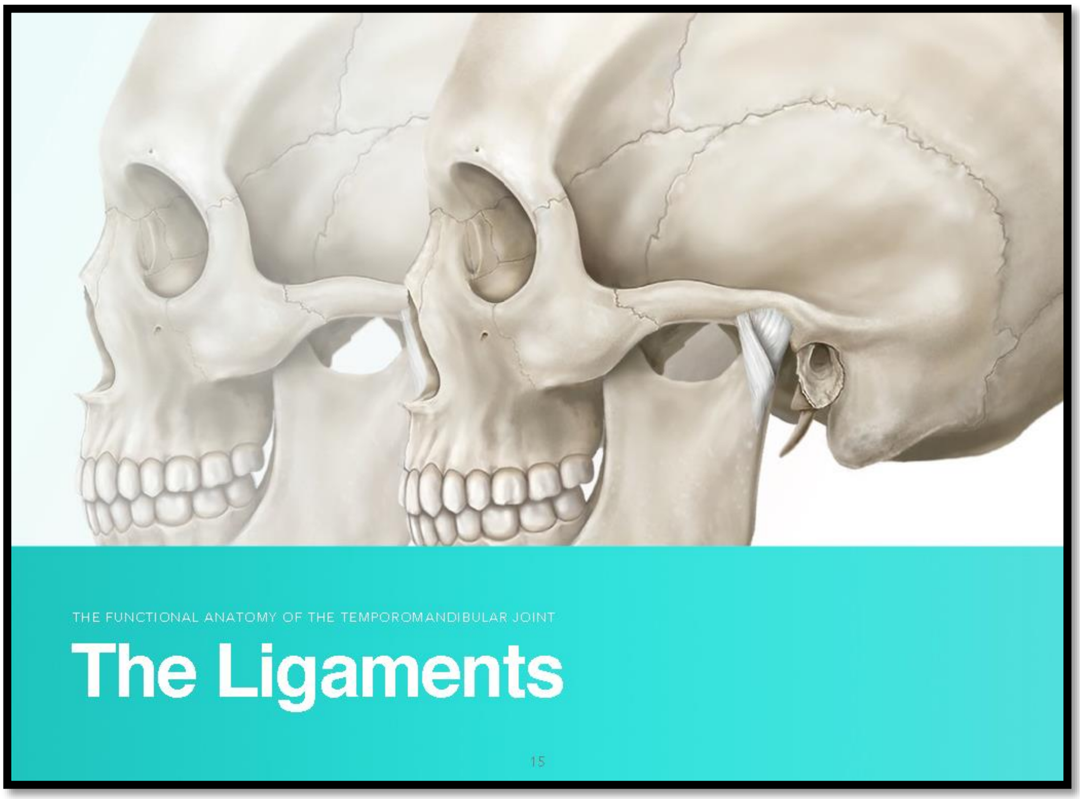
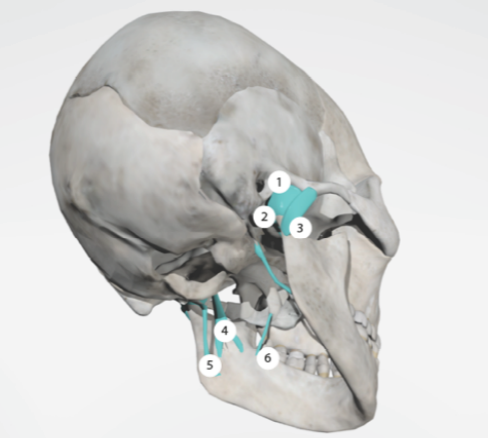

THE FUNCTIONAL ANATOMY OF THE TEMPOROMANDIBULAR JOINT
The Ligaments
15

CHAPTER TWO

The Ligaments



Inferior lateral view

Ligaments support the TMJ.

The function of the ligaments is to protect the TMJ by limiting the movements of the joint. The temporomandibular joint is protected by six groups of ligaments: three directly associated with TMJ and three remote accessory ligaments.

TMJ ligaments

1. The capsular ligament
2. The discal ligament
3. The temporomandibular ligament

Accessory ligaments

4. The sphenomandibular ligament
5. The stylomandibular ligament
6. Pterygomandibular raphe

CHAPTER TWO : THE LIGAMENTS

The Capsular Ligament

The **fibrous capsule** itself acts as a ligament.

It's fibres originate superiorly on the temporal bone along the borders of the articular surface of the glenoid fossa. The fibres insert in the neck of the condyle allowing the ligament to resist medial, lateral or inferior forces.

Its functionality avoids dislocation of the articular surfaces and retains the synovial fluid that keeps the joint lubricated.

Proprioception of the position and movement of the joint is given by receptors in this ligament.

Antero-lateral view | Lateral view | Inferior view

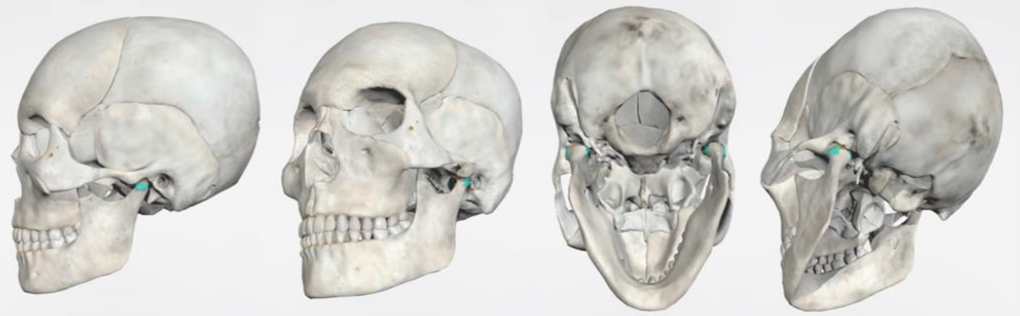
The Discal Ligament

These are two small ligaments:

The **medial discal ligament** attaches the medial edge of the disc to the medial pole of the condyle.

The **lateral discal ligament** attaches the lateral pole of the condyle with the lateral portion of the disc.

The function of these ligaments is to restrict the medial or lateral movement of the disc, while still allowing the disc to move anteriorly and posteriorly during the hinge and sliding movement of the joint.

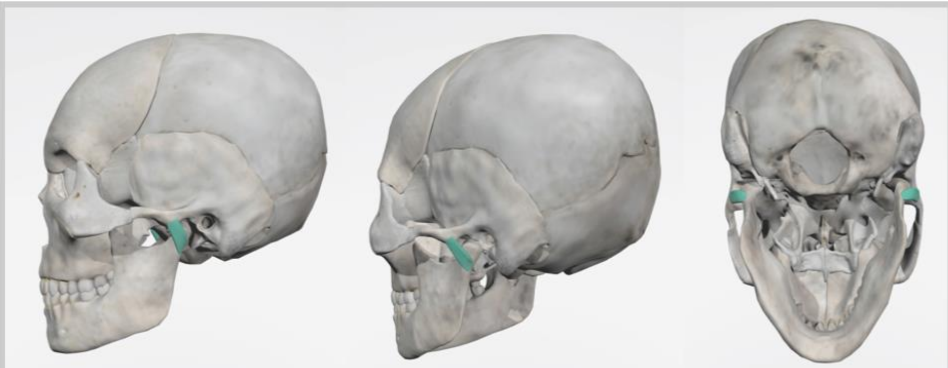


Lateral view | Antero-lateral view | Inferior view | Postero-lateral view

The Temporomandibular Ligament

The **temporomandibular ligament** originates on the lateral aspect of the articular eminence. It fibres follow an oblique direction which then insert on the posterior surface of the neck of the condyle.

This ligament restricts posterior, lateral and inferior movement of the condyle. In addiction, it restricts medial movement of the contralateral condyle.



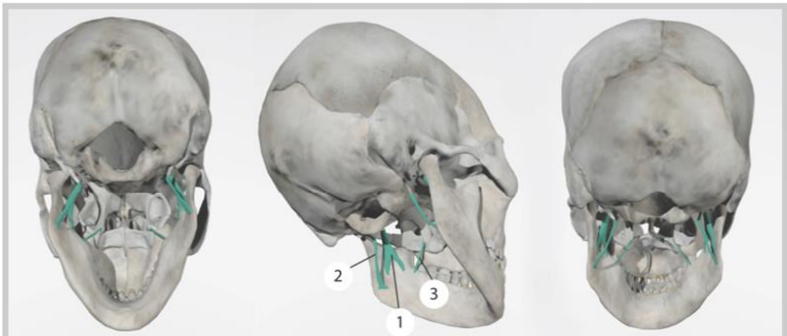
Lateral view | Postero-lateral view | Inferior view

CHAPTER TWO : THE LIGAMENTS

The Accessory Ligaments

The TMJ has three accessory ligaments:

1. The **sphenomandibular ligament** originates at the spine of the sphenoid bone and inserts in the lingula located in the inner part of the ramus.
2. The **stylomandibular ligament** originates at the styloid process and extends downwards and forward to the medial aspect of the angle of the mandible. It's function is to restrict the protrusive movement of the mandible.
3. The **pterygomandibular raphe** originates from the pterygoid hamulus and extends to the retromolar region. The raphe is a landmark for local anaesthesia. It is also the origin of the Buccinator and superior pharyngeal constrictor muscles.



Inferior view (Open) Inferior-lateral view Inferior view (Close)

CHAPTER TWO : THE LIGAMENTS

Quiz

Question 1 of 4

Which movements of the mandible are restricted by the temporomandibular ligament?

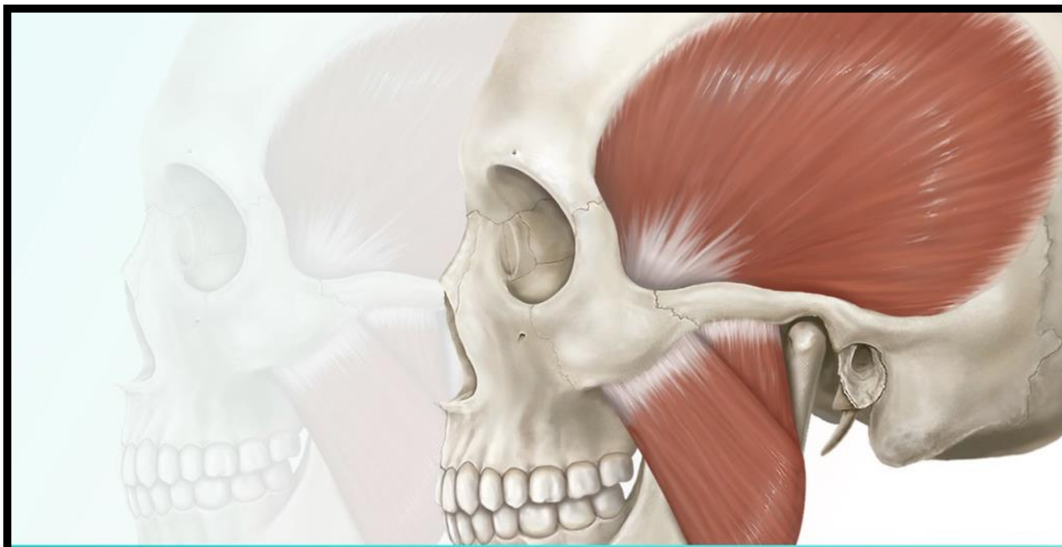
- A. Posterior
- B. Inferior
- C. Lateral
- D. All of the above

Suggested website...

https://www.innerbody.com/

Suggested readings...

http://jaoa.org/article.aspx?articleid=2094120



THE FUNCTIONAL ANATOMY OF THE TEMPOROMANDIBULAR JOINT

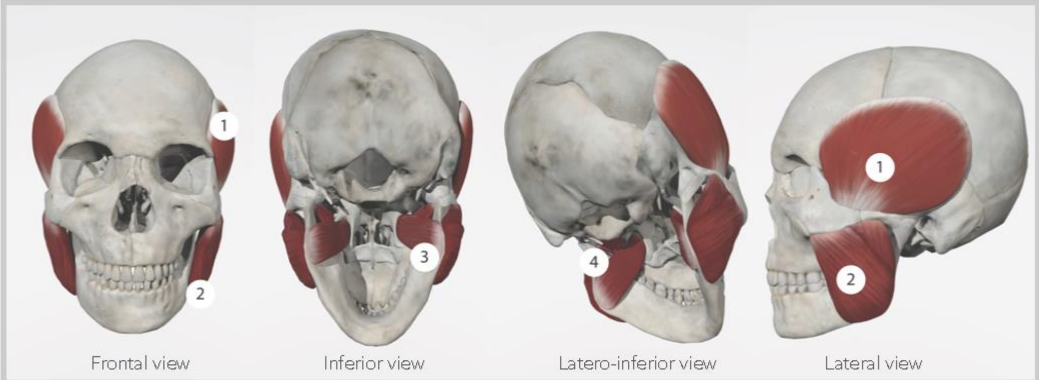
The Muscles

CHAPTER THREE

The Muscles

There are five main muscles involved in mastication:

The masseter, temporalis, medial pterygoid, lateral pterygoid and digastric.



1. Left temporalis, 2. Left masseter; 3. Right lateral pterygoid; 4. Left Medial pterygoid

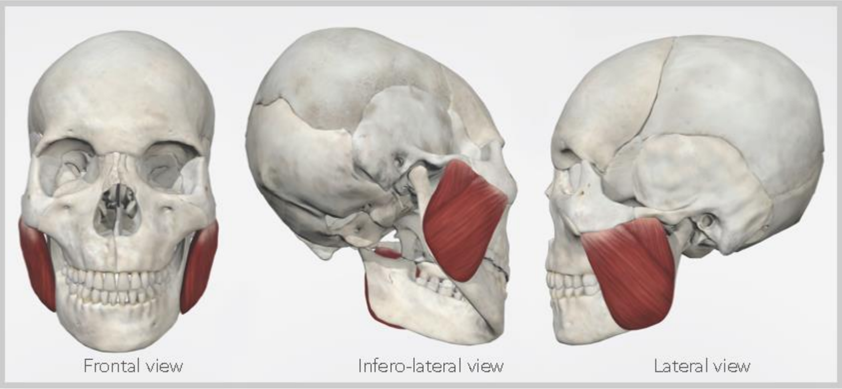
CHAPTER THREE : THE MUSCLES

The Masseter

The **masseter** originates at the zygomatic arch and bone and inserts onto the lateral aspect of the lower border and angle of the ramus of the mandible.

The superficial fibres run downward and backwards. While the deep fibres run vertically to the insertion area.

Its main function is to elevate the mandible. As a secondary function the superficial fibres are active during protrusion. The masseter is innervated by the masseteric nerve and blood supplied by the masseteric artery.



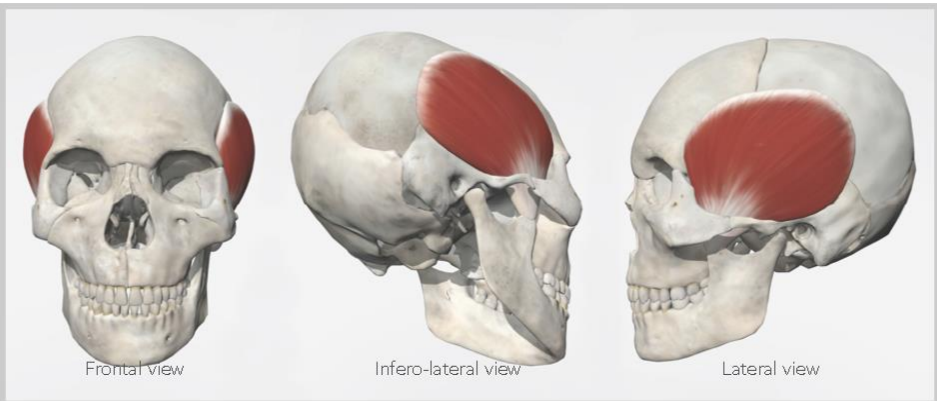
CHAPTER THREE : THE MUSCLES

The Temporalis

The **temporalis** originates from the inferior temporal line and fossa and the lateral surface of the skull. It is a fan-shape muscle that inserts onto the coronoid process and anterior border of the ascending ramus.

Its function is to elevate the mandible but its horizontal fibres help with retrusive movements.

The temporalis is innervated by the deep temporal nerve branch of the trigeminal nerve. Blood supply is given by the anterior, posterior and superficial temporal arteries.



The Medial Pterygoid

The **medial pterygoid** has two heads; the main one originates from the medial aspect of the lateral pterygoid plate, the minor head originated form the maxillary tuberosity. The fibres then insert onto the medial surface of the angle of the mandible following a downwards, backward and outward direction.

Its primary action is to elevate the jaw and also aids protrusive movements and, if unilateral contraction, lateral excursions of the mandible. Blood supply is given by the pterygoid brach of the maxillary artery. It is innervated by medial pterygoid nerve.

Lateral view Postero-lateral view Posterior view (Open) Inferior view

The Lateral Pterygoid

The **lateral pterygoid** is a complex and poorly understood muscle. It has two heads that appear to function differently. These are the superior lateral pterygoid and the inferior lateral pterygoid.

Lateral view Lateral view (Open) Inferior view Infero-lateral view

CHAPTER THREE : THE MUSCLES

The Lateral Pterygoid Inferior Head

The **inferior head of the lateral pterygoid** originates from the lateral surface of the lateral pterygoid plate and inserts into the pterygoid fovea on the neck of the condyle.

Its main function is to protrude the mandible when it contracts bilaterally. However, when one side contracts, the mandible moves to the opposite side. When working in conjunction with jaw depressor muscles it facilitates wide opening.

CHAPTER THREE : THE MUSCLES

The Lateral Pterygoid Superior Head

The **superior head of the lateral pterygoid** is smaller than than the inferior head. This section originates in the infra-temporal surface of the greater sphenoid wing and inserts onto the articular capsule and the disc of the TMJ.

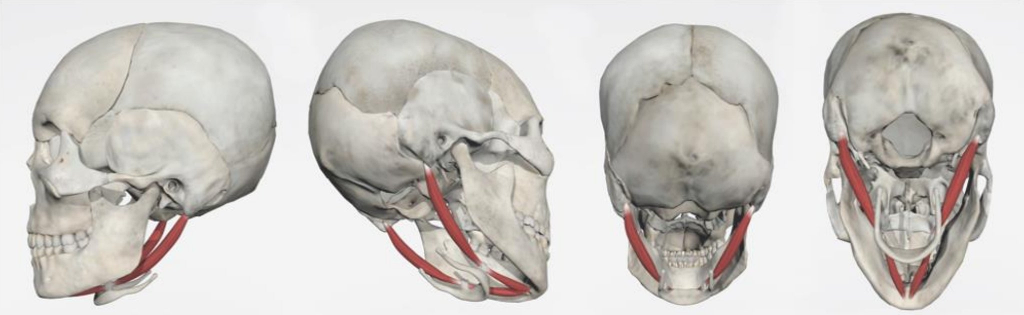
This muscle is active during closing movement of the mandible. It is especially active when maximum bite force is generated, for example during clenching. Therefore, it can be symptomatic in patients with TMJ disorders.

The Digastric

The **digastric muscles** is involved in jaw opening movement. It has two bellies - anterior and posterior.

Its anterior belly originates from the digastric fossa of the mandible and the posterior belly originates from the mastoid notch. Both insert into the intermediate tendon that is attached to the hyoid bone by a fibrous loop.

When the hyoid bone is fixed, the anterior belly acts as a jaw depressor. If the hyoid bone is not fixed, the digastric muscles act to raise the hyoid bone during swallowing.



Lateral view | Infero-lateral view | Posterior view | Inferior view

Quiz

Question 1 of 4

Regarding the masseter muscle.

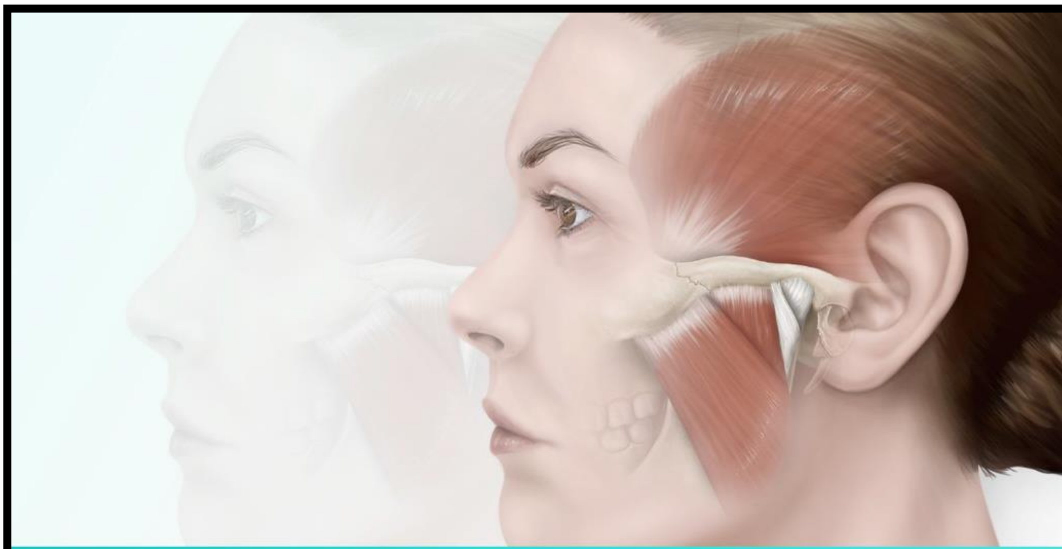
- **A.** It contributes to jaw opening during mastication
- **B.** Its superficial fibres insert in the anterior border of the ramus
- **C.** Its deep fibres run vertically
- **D.** Contraction of superficial fibres help retrusive jaw movements

Suggested website...

https://www.innerbody.com/anatomy/muscular/head-neck

Suggested readings...

Chapter 1. Management of temporomandibular disorders and occlusion. Jeffrey P. Okeson



THE FUNCTIONAL ANATOMY OF THE TEMPOROMANDIBULAR JOINT

The Joint

CHAPTER FOUR: THE JOINT

The Temporomandibular Joint

The **TMJ** is a complex and unique joint:

1. The TMJ essentially a double joint – in that both TMJs must move together
2. TMJ movement is, in part, guided by the teeth
3. It has a two-compartment joint space, divided by a disc
4. It is capable of complex hinging, sliding and rotational movements

The TMJ is mainly innervated by auriculotemporal nerve.

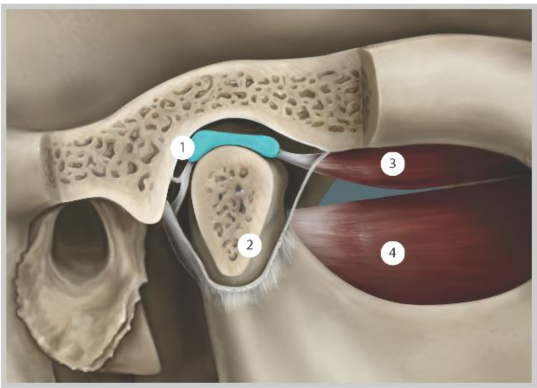
The Articular System

The condyle-disc complex articulates with the glenoid fossa of the temporal bone. The disc is intimately attached to the condyle so it can only rotate in the articular surface of the condyle. However, as the disc is not tightly attached to the glenoid fossa, sliding and free translation of the condyle-disc complex can occur. Both systems are attached to each other mainly ligaments - including the capsule.

The Disc

The **articular disc** is a dense fibrous disc that has two parts:

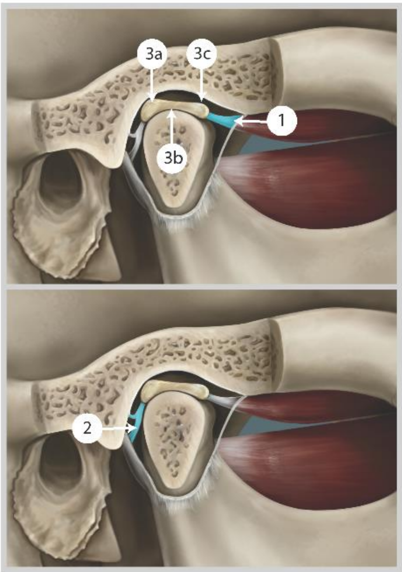
1. Upper part; allows hinge movements of the jaw
2. Lower part; functions during slide movements of the mandible



1. Disc; 2.Condyle; 3. Superior Lateral Pterygoid; 4. Inferior Lateral Pterygoid

The Disc

The Disc

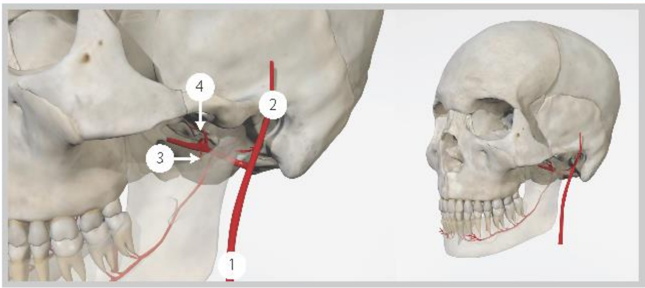


The articular disc has 5 zones

1. Anterior extension - is continuous with the superior head of the lateral pterygoid
2. Posterior extension - is densely innervated and has two layers:
   a. The upper layer which is vascular and elastic
   b. Lower layer which is fibrous.
3. Disc
   a. Posterior band
   b. Intermediate zone
   c. Anterior band

CHAPTER FOUR: THE JOINT

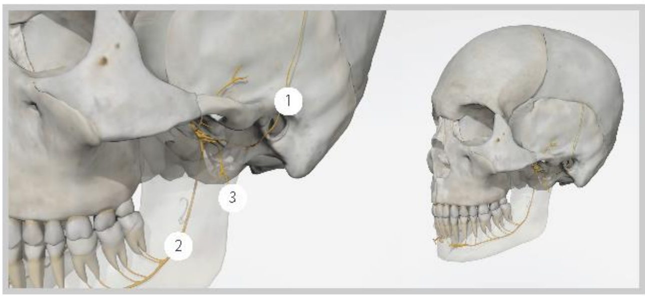
Blood supply and innervation



Blood Supply

The TMJ has a rich blood supply. It is supplied by the superficial temporal artery but also branches off the medial meningeal, the maxillary artery among others.

1. External carotid artery
2. Superficial temporal artery (cut)
3. Maxillary artery (cut)
4. Meningeal artery



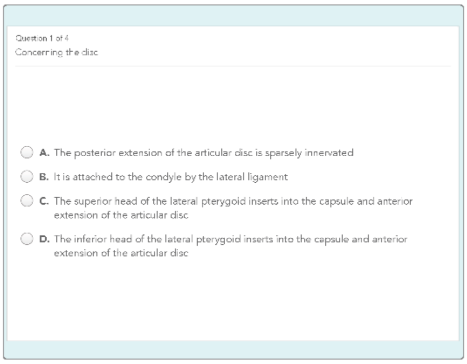
Innervation

The TMJ is innervated by the auriculotemporal nerve. In addition it is also supplied by branches of the deep temporal masseteric nerve. These are all branches of the mandibular division of the trigeminal nerve.

1. Auriculotemporal nerve
2. Inferior alveolar nerve
3. Masseteric nerve

CHAPTER FOUR: THE JOINT

Quiz



Question 1 of 4
Concerning the disc

- A. The posterior extension of the articular disc is sparsely innervated
- B. It is attached to the condyle by the lateral ligament
- C. The superior head of the lateral pterygoid inserts into the capsule and anterior extension of the articular disc
- D. The inferior head of the lateral pterygoid inserts into the capsule and anterior extension of the articular disc

Good Job!

Suggested website...

https://www.innerbody.com/

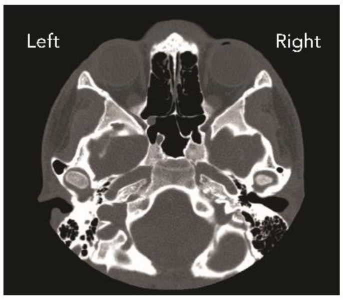
Suggested readings...

https://www.researchgate.net/publication/268449085_Functional_Anatomy_of_the_TMJ

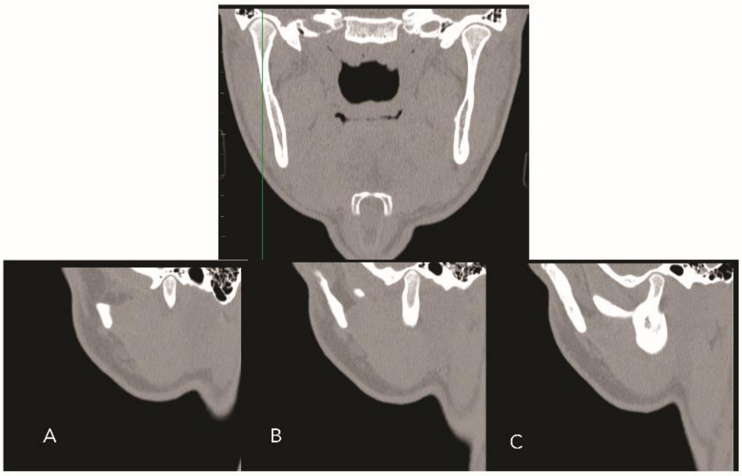
APPENDIX 10: ASSESSMENT TOOL USED IN THE TMJ STUDY

Test

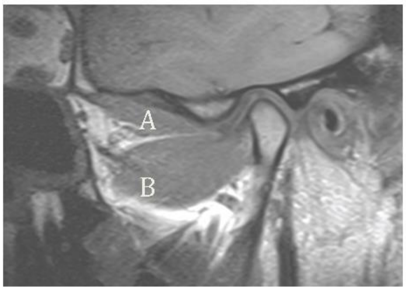
1. In the horizontal section below the patient shown in the CT scan has his mouth closed. If simultaneous contraction of the inferior head of the lateral pterygoid occurs and a second the same image is taken in the same position, would you see?
   A) A bigger section of the left condyle
   B) A smaller section of the left condyle
   C) The same proportion of the left condyle



2. Please match the following coronal plane cut with its corresponding sagittal plane view.



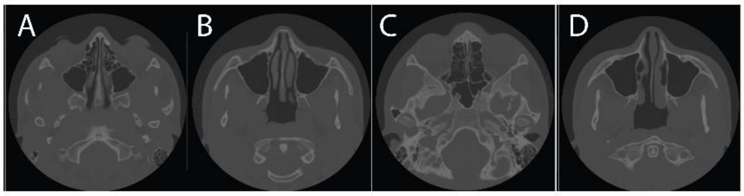
3. Identify the muscles spotted A and B



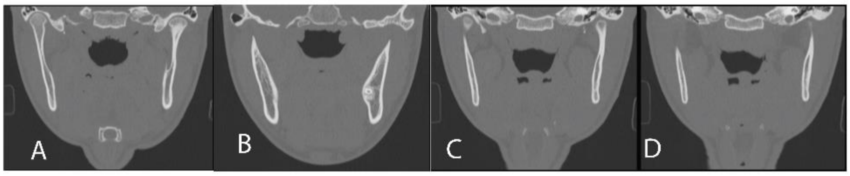
Muscle A:______________________

Muscle B:______________________

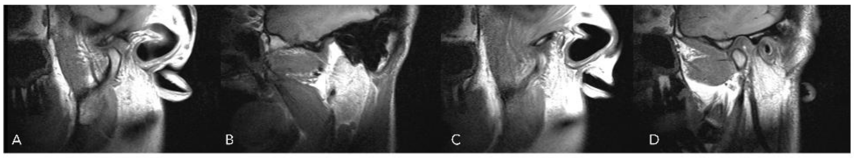
4. Please provide the correct sequence starting from the most superior cut



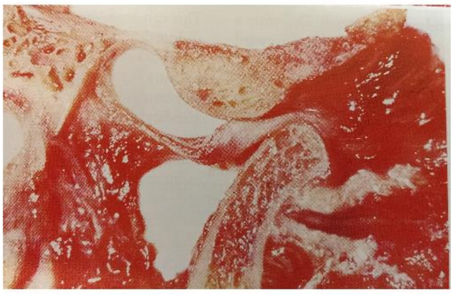
5. Please provide the correct sequence starting from the most posterior cut



6. Please provide the correct sequence starting from the most external cut



7. What ligament limits this extreme movement of the condyle?



A. Capsular ligament
B. Temporomandibular ligament
C. Discal ligaments
D. Sphenomandibular ligament

8.
a) Concerning the muscles of the TMJ, please indicate.

Image 1

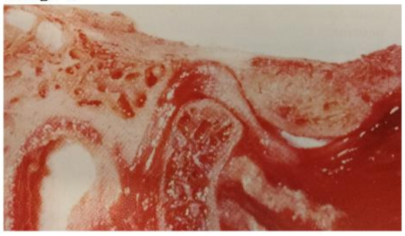
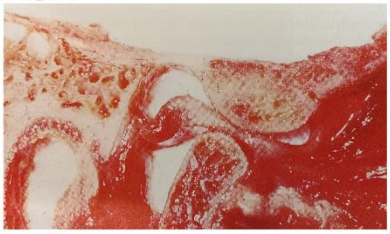


Image 2

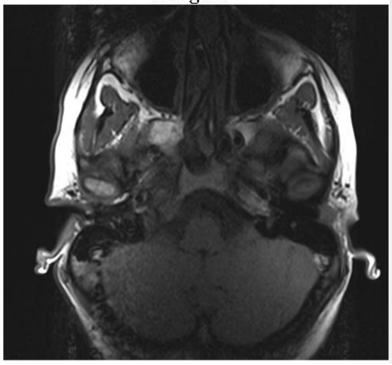


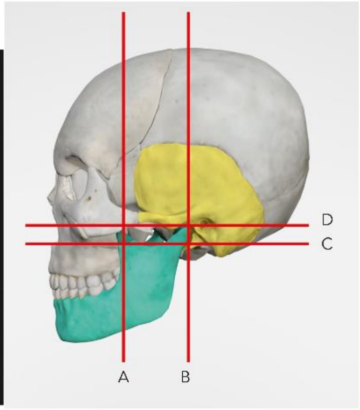
	Movement of the condyle	Muscle principal movement	True or False
A	Image 1 ➔ Image 2	Superior lateral pterygoid	
B	Image 1 ➔ Image 2	Inferior lateral pterygoid	
C	Image 2 ➔ Image 1	Medial pterygoid	
D	Image 2 ➔ Image 1	Digastric	
E	Image 2 ➔ Image 1	Masseter	
F	Image 1 ➔ Image 2	Temporalis	

b) Which movements are represented by the sequence given by Photo 1 and 2 above?
A. Protrusive, opening and left lateral
B. Retrusive, opening and right lateral
C. Protrusive, closing and right lateral
D. Retrusive, closing and left lateral

9. Please identify the plane (A, B, C or D) corresponding to the image 1.

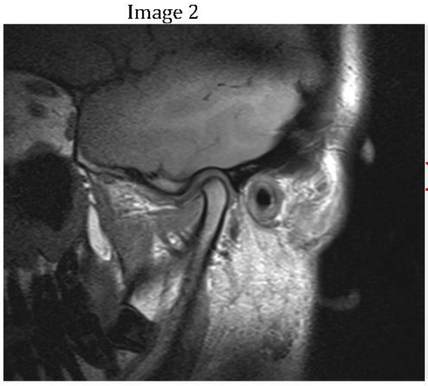
Image 1

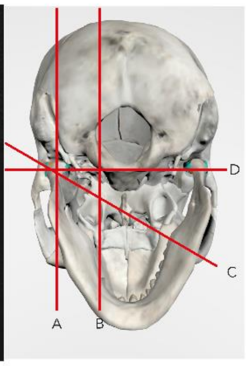




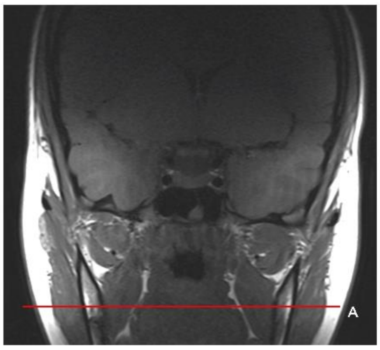
10. Please identify the plane (A, B, C or D) corresponding to the image 2.

Image 2





11. Please identify the masticatory muscles sectioned by plane A.



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APPENDIX 11: ETHICAL APPROVAL LETTERS

STUDY CHAPTER 3

Re: UREC 13084-approved

Astrid Schloerscheidt
Sent:05 August 2013 11:04
To: Paulina Poblete Pacheco

Hi Paulina,

yes, you can go ahead with the focus groups, that is no problem.

Best,

Astrid

Dr. Astrid Schloerscheidt
School of Psychology
University of Dundee
phone: 01382-384595

On 5 Aug 2013, at 11:02, Paulina Poblete Pacheco wrote:

> Dear Astrid,
>
> Many thanks for your prompt response.
>
> I will collect the documents proving the consent of the other Universities in participating in the survey. Also, before targeting the survey participants I will show you the final constructed questionnaire.
>
> Meanwhile, as in the first stage (focus groups) I will only work with Dundee students, may I start with my data collection?
>
> Many thanks,
>
> Paulina.
> ____
> From: Astrid Schloerscheidt
> Sent: 04 August 2013 11:42
> To: Paulina Poblete Pacheco
> Cc: Astrid Schloerscheidt; Elizabeth Evans
> Subject: Re: UREC 13084-approved
>
> Dear Paulina,
>
> many thanks for the answers to my questions and the revisions to the documents. Your study is approved under the condition that you send me the final survey for approval before you start recruitment for this part of your study.
>
> Once you have had an opportunity to obtain written documentation that you are allowed to approach students and graduates from the other Universities, I would also need to have copies of these. Again, approval of your study is conditional on receiving these.
>
> Best,

\>
\> Astrid
\>
\>
\> On 1 Aug 2013, at 15:03, Paulina Poblete Pacheco wrote:
\>
\>> Dear Astrid,
\>>
\>> Hope you are fine when receiving this email.
\>>
\>> I made the suggested changes to my proposal. Please find attached a file with the documents.
\>> Please do not hesitate in contacting me if any further suggestion comes forward.
\>>
\>> Best regards,
\>>
\>> Paulina.
\>> ____
\>> From: Astrid Schloerscheidt
\>> Sent: 30 July 2013 13:40
\>> To: Paulina Poblete Pacheco
\>> Subject: Re: UREC 13084
\>>
\>> Hi Paulina,
\>>
\>> no worries and no hurry. There is no time limit. You can send the revision whenever you have had time to do them.
\>>
\>> Best,
\>>
\>> Astrid
\>>
\>>
\>> Dr. Astrid Schloerscheidt
\>> School of Psychology
\>> University of Dundee
\>> phone: 01382-384595
\>>
\>>
\>>
\>>
\>>
\>>
\>>
\>> On 30 Jul 2013, at 13:35, Paulina Poblete Pacheco wrote:
\>>
\>>> Dear Astrid,
\>>>
\>>> Many thanks for your email.
\>>>
\>>> Sorry for my late response. I just came back today from my annual leave holidays. I will work on the details you requested and I will send them back to you as soon as possible.
\>>>
\>>> Best regards,
\>>>
\>>> Pualina.
\>>> ____
\>>> From: Astrid Schloerscheidt
\>>> Sent: 12 July 2013 20:02

>>> To: Paulina Poblete Pacheco
>>> Cc: Astrid Schloerscheidt
>>> Subject: UREC 13084
>>>
>>> Dear Paulina,
>>>
>>> I have now had a chance to review your ethics application. My sincerest apologies for the delay in getting back to you.
>>>
>>> There are no ethical issues with your research. I would, however, request some small change to some of the documentation, before I can approve your study.
>>>
>>> Could you please provide information in the study protocol how you intend to recruit participants for the focus groups and the surveys. The protocol sounds as if you will be selectively targeting students and academics, which I assume is not what you intend to do. Could you please clarify? Could I also ask that you do not approach students face-to face.
>>>
>>> Are you in any way involved in the teaching and assessment of the students you intend to recruit? If so, could you please consider the potential issues of coercion. Students may feel uncomfortable not taking part in a research study if the researcher is directly involved in their assessment.
>>>
>>> Do you intend to audio-record the focus groups? If so, this needs to be made clear in the information sheet and if this is the case, a tick-box needs to appear on the consent form that participants agree to the audio-recording. If you do not audio-record, how will you collect the data? What data are you going to collect and where and for how long will you store it? You should also add this information to the information sheet for the participants of the focus groups.
>>>
>>> I will also need to see the final survey that you plan to put online before you start recruitment for the survey. Additionally, I would need to see evidence that the other dental schools are happy for you to approach their academics, students and graduates.
>>>
>>> You can send the amended documentation to me directly by email. I should then, hopefully, be in a position to approach your study soonest.
>>>
>>> Best regards,
>>>
>>> Astrid
>>>
>>> Dr. Astrid Schloerscheidt
>>> Chair, University of Dundee Research Ethics Committee
>>>
>>>
>>>
>>
>> <Suggested correction proposal Ethical approval.docx><Phase 1 Ethics (2).zip>
>
>

STUDY CHAPTER 8

School of Psychology

University of Dundee Research Ethics Committee

University of Dundee
Dundee
DD1 4HN

5th January 2015

Dear Ms Poblete,

Application Number: UREC 14173

Title: Dental students' perceptions of an iBook covering tooth morphology

I am writing to you to advise you that your ethics application has been reviewed and approved by the University of Dundee Research Ethics Committee.

Approval is valid for three years from the date of this letter. Should your study continue beyond this point, please request a renewal of the approval.

Any changes to the approved documentation (e.g., study protocol, information sheet, consent form), must be approved by UREC.

Yours sincerely,

Dr Astrid Schloerscheidt
Chair, University of Dundee Research Ethics Committee

UNIVERSITY OF DUNDEE Dundee DD1 4HN Scotland UK t +44(0)1382 229993
e psych@dundee.ac.uk www.dundee.ac.uk/psychology

STUDY CHAPTER 10

School of Psychology

UNIVERSITY OF DUNDEE

University of Dundee Research Ethics Committee

University of Dundee,
Dundee,
DD1 4HN.

2 December 2015

Dear Paulina

Application Number: UREC 15114

Title: Comparing the use of 3D versus 2D using an Temporomandibular Joint iBook

I am writing to you to advise you that your ethics application has been reviewed and approved by the University of Dundee Research Ethics Committee.

Approval is valid for three years from the date of this letter. Should your study continue beyond this point, please request a renewal of the approval.

Any changes to the approved documentation (e.g., study protocol, information sheet, consent form), must be approved by UREC.

Yours sincerely,

A. Schloerscheidt

Dr Astrid Schloerscheidt
Chair, University of Dundee Research Ethics Committee

UNIVERSITY OF DUNDEE Dundee DD1 4HN Scotland UK t +44(0)1382 229993
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APPENDIX 12: COMPLETE PERCEPTION QUESTIONNAIRE CHAPTER 10

Anatomy of the TMJ and the masticatory system

Please choose the best answer for each of the following statement

	Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
The Anatomy of the TMJ and the masticatory system iBook is easy to use	○	○	○	○	○
The content is well designed	○	○	○	○	○
The use of the Anatomy of the TMJ and the masticatory system iBook has facilitated my studies	○	○	○	○	○
This teaching method motivates me to learn	○	○	○	○	○
The volume of information is appropriate	○	○	○	○	○
I am satisfied with the 360 degree rotation models	○	○	○	○	○
The 3D content is of high quality	○	○	○	○	○
I have enjoyed learning Anatomy of the TMJ and the masticatory system with the 3D interactive iBook	○	○	○	○	○
Learning Anatomy of the TMJ and the masticatory system seems easier with a 3D iBook than with textbook	○	○	○	○	○
The Anatomy of the TMJ and the masticatory system iBook should be made available on blackboard for all dental students	○	○	○	○	○

Concerning the Pre-test / Post-test

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I feel the test measured my 3D knowledge	○	○	○	○	○
My responses were influenced heavily by my previous knowledge on the subject	○	○	○	○	○

Concerning the time given to use the iBook. Do you think:

- ☐ Time was right and appropriate
- ☐ It was to much time
- ☐ The session was too short, I would need more time

Gender

- ☐ Male
- ☐ Female